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Conceptualizing Pedagogical Content Knowledge from the Perspective of

Experienced Secondary Science Teachers

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Conceptualizing Pedagogical Content Knowledge from the Perspective of Experienced Secondary Science Teachers

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Dissertation

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Doctor of Philosophy

The University of Texas at Austin

May 2005

This work is dedicated

to my mother Ok-Soon Kang for giving me immeasurable love and sacrifice,

to my husband Ji-Hoon Kim for being the greatest company and supporter, and

to my son Richard Young-Jae Kim for being the source of joy

in each step of this marvelous journey.

Acknowledgments

Above all I thank God to guide me every moment in my life. I know that it's a blessing from You that there are so many people to whom I owe thanks and gratitude for guiding me and supporting me throughout this incredible five year journey.

First of all, I would like to thank the four participants in this study for sharing their thoughts and practices with me during the interviews and classroom observations. I hope that the moments we shared will benefit them and their future teaching. I would also like to thank the "Teachers as Mentors" project director Peggy Carnahan for allowing me to study with the participants of the program and for helping me in many ways.

I am forever in debt to my supervisor and mentor, Dr. Julie A. Luft. Whenever I felt overwhelmed or depressed, I was able to get over it, thanks to her emotional support and practical guidance. Without her constant support and feedback, I would not have been able to finish this study. I sincerely hope to continue working with her in the future. Julie, you are my role model as a teacher educator and mentor.

I offer deep gratitude to the other members of my committee who provided me much needed encouragement throughout the last two years: Dr. Barufaldi and Dr. Bethel, I will forever bear in mind your untiring support and encouragement throughout all my time at UT. Dr. Northcutt, I will remember your help and prompt feedback. Dr. Carol Fletcher, I will keep in mind all the moments that I worked with you.

I am very thankful for the insightful advice I received from Julie Guess-Newsome at Northern Arizona University. She helped me pin down the research question for this dissertation at the beginning, and her feedback made it possible for me to complete this study in time. Julie, I plan to conduct further research on the questions that remain.

I would like to thank the staff in the Center for Science and Mathematics Education — Gail Seal, Jim Gross, and Sonya Willis — for their emotional support and practical help during my time in graduate school. Gail, Jim, and Sonya, everything that I have done at graduate school was possible thanks to you.

I would also like to thank my Texas Regional Collaboratives (TRC) family, including Dr. Kamily Jeily, Sandy Willkins, Joel Blasingame, Marsha Willis, and Kris Mason. The past two years with the TRC provided me lots of experience and pleasure. The lessons that I learned through working with you will greatly benefit my future life and work.

I would like to thank Chris Dolejs and Laura Havlick for carefully reading my draft and editing it. Your services provided me comfort and confidence when publishing the draft.

I am very thankful for the friendship and support that I have received from my fellow graduate students Magnia, La Vergne, Yu-mei, Marsha, Bhaskar, Luis, Brian, Janice, Barbra, Heejoon, Sera, Mischelle, Steve, Pete, and Jeff. Guys, our relationship as colleagues and friends in Science Education will be forever, won’t it?

I have been so fortunate to be surrounded by many Korean friends here in Austin: Dongrhin, Jeong-Eun, Eunjeong, Jaehee, Mi-Ae, Eun-A, Hyejeong, Sun-A, and Mijeong. The moments that I shared with you guys during the last five years have been the most valuable memories. I hope to have a chance to give back the love and support I have gotten from you. You will forever be with me in my heart and prayers.

I am blessed with the greatest family. Their prayers and love were the driving force toward my success. I especially thank my mother who is with me no matter where I go. Your endless self-sacrifice and love brought my life so many things, including this Ph.D degree. Mom, I love you forever and ever.

Finally, I must thank my husband and my son. I can't find the words to express my thanks for my husband, Jihoon Kim. The love and support he provided me is beyond words. You showed me how to love by putting up with all my unreasonable behaviors, frustrations, angers, and tears countless times. I am now ready to switch to that role as you complete your dissertation. My eight-month-old son is the source of my energy and joy. He even gave me company during the trip for the final interview and kept the driving safe. I know that. Youngjae, my life has been more blessed because of you. I love you through and through.

Conceptualizing Pedagogical Content Knowledge from the Perspective of Experienced Secondary Science Teachers

Publication No. _________

Eunmi Lee, Ph.D.

The University of Texas at Austin, 2005

Supervisor: Julie A. Luft

Since the concept of pedagogical content knowledge (PCK) was introduced, educational researchers have attempted to describe and capture the PCK of teachers. However, researchers have failed to reach a consensus in understanding PCK. In an effort to contribute to the literature that conceptualizes PCK, this study investigates how experienced secondary science teachers, serving as mentors to beginning science teachers, represent PCK. Data include semi-structured interviews, classroom observations, lesson plans, and reflective summaries. A case study method was utilized to conduct an in-depth investigation focusing on how the four experienced secondary science teachers revealed PCK throughout their teaching practices. Grounded theory was employed as the analytic framework for the study. The findings of this study reveal that the experienced teachers' PCK commonly includes

knowledge of: (1) science; (2) goals; (3) students; (4) curriculum organization; (5) assessment strategies; (6) teaching strategies; and (7) resources, with specific elements within each component. Based on the interpretation of the data in the study, the seven components were transformed into each teacher's PCK that represented his or her own expertise, which ultimately functioned as a filter to determine his or her instructional decisions and actions. The PCK conceptualization of each teacher varied, depending upon his or her individual background and teaching situation. This study shows that the concept of PCK is not only a unique knowledge required for teaching science, but also the application of thatknowledge into teaching practice.

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CHAPTER ONE

INTRODUCTION

> Perhaps there is the assumption that nobody ever has asked this particular research question in quite the same way, so it is as yet impossible to determine which variables pertain to this area and which do not. This reasoning creates the need for asking a type of question that will enable researchers to find answers to issues that seem important but remain unanswered (Strauss & Corbin, 1998, p 40).

Introduction

The American Association for the Advancement of Science (AAAS, 1989) states:

> Although creative ideas for reforming education come from many resources, only teachers can provide the insights that emerge from intensive, direct experience in the classroom itself. They bring to the task of reform knowledge of students, craft, and school structure that others cannot (p. 155).

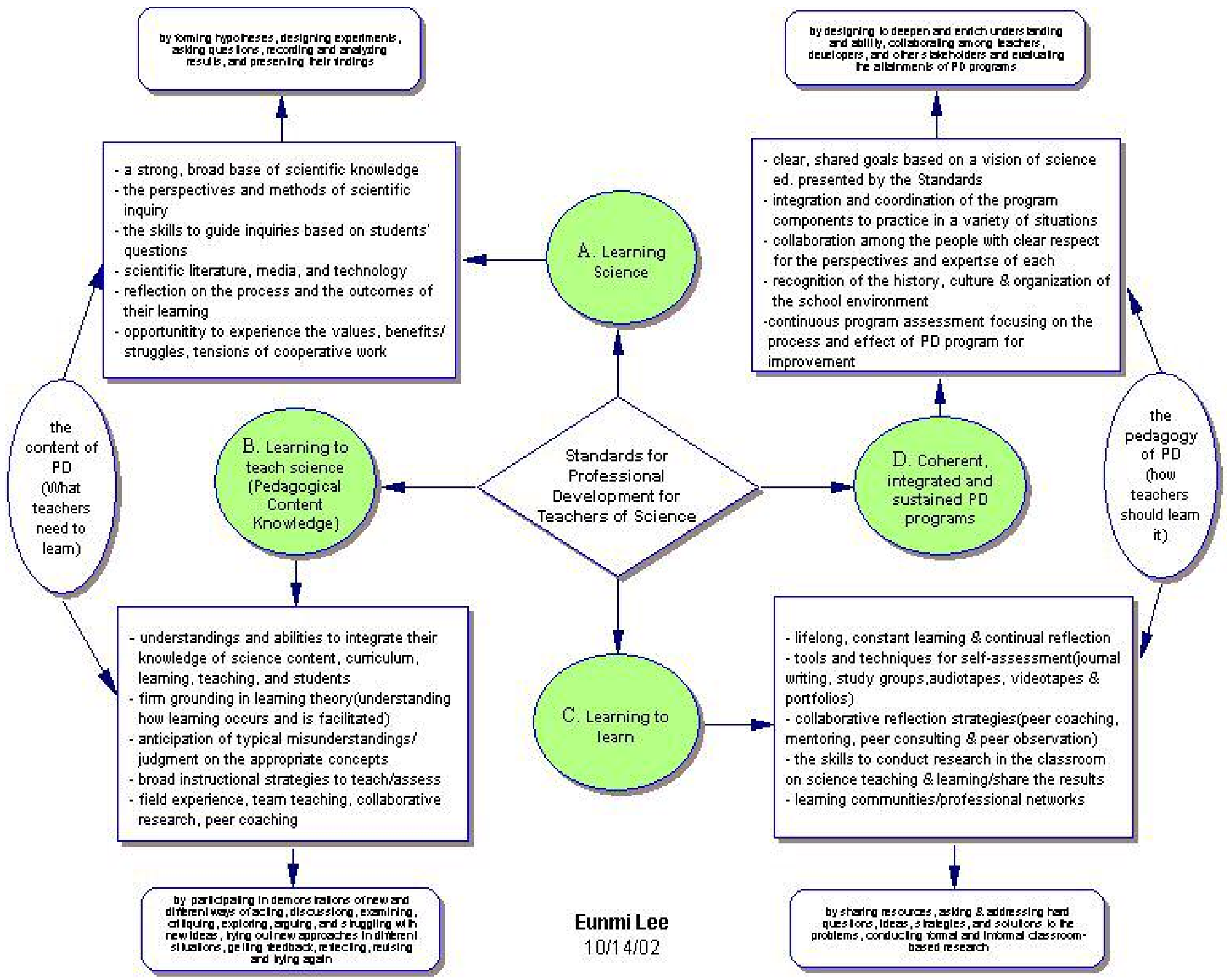
This statement clearly indicates the crucial role a science teacher would play in implementing reform. Considering a teacher as a core agent in taking action in reform, we acknowledge the basic assumption that teachers possess a body of specialized knowledge acquired through the years of teaching experience and a variety of training just as in other professions, such as architects, doctors, and lawyers. On the basis of this knowledge, which distinguishes teachers from other professionals, teachers can make pedagogical reasoning and decisions in their practice that will ultimately enhance their students' understanding of science.

What does a teacher need to know in order to teach science? The answer depends largely on the identity of the respondent. Some might suggest that content knowledge is important, while others indicate that pedagogical knowledge or other factors are essential to teaching. Another area that has recently gained more attention is Pedagogical Content Knowledge (PCK). Along with the emphasis on teaching as a unique professional status, teachers' knowledge and beliefs have been identified as PCK in discussions among science teacher educators over the past few years (Gess-Newsome& Lederman, 1999). PCK is the unique combination of content and pedagogical knowledge that helps teachers transform science content into learning experiences for students. Additionally, standard documents in science education put great emphasis on developing teachers' PCK as the crucial element of an effective reform effort.

The National Science Education Standards document (National Research Council [NRC], 1996) explicitly proposes two dimensions of science teachers' professional development: content — what teachers need to know — and pedagogy — how teachers should learn what they need to know (Bybee & Loucks-Horsley, 2001). Learning science and learning to teach science fall into the former category (Figure 1). This seminal document clearly indicates that having a solid understanding of science content and the nature of science is not guaranteed to make one a skilled teacher of science. Science teachers must also possess the special knowledge that allows them to tailor science learning to the needs of individuals and groups. This special knowledge — called PCK — differentiates the expertise of science teachers from that of scientists (Cochran, DeRuiter, & King, 1993; Grossman, 1990; NCR, 1996; Shulman, 1986; 1987).

Shulman (1986) first introduced PCK as a specific category of teacher knowledge “which goes beyond knowledge of subject matter per se to the dimension of subject matter for teaching” (p.9). Since the concept of pedagogical content knowledge was introduced, education researchers have attempted to describe and conceptualize the PCK of teachers. In recent years, research in this domain has significantly promoted the understanding of the elements that forms teachers’ knowledge. At this time, however, it is still difficult to explicitly identify and assess teachers’ PCK because PCK is a complex notion and science teachers themselves do not use this term (Loughran, Milloy, Berry, Gunstone, and Mulhall, 2001; Van Driel, Beijaard, and Verloop, 2001).

Figure 1. The framework of the Standards (NRC, 1996) for professional development



Statement of the Problem

The PCK of expert science teachers is an integrated understanding of teaching science through "trial and error in teaching situations, continual thoughtful reflection, interaction with peers, and much repetition of teaching science content" (NRC, 1996, p.67). Given the field-based nature of this concept, perhaps out best representation is within experienced science teachers. Experienced science teachers may have more developed PCK. Therefore, the goal of this study is to explore the concepts of PCK among experienced secondary science teachers who are serving as mentors for those who are in the beginning stage of science teaching in secondary schools. The focus will be on categorizing PCK by exploring these teachers' conceptualization of PCK, specifically as it pertains to secondary science teachers' expertise, acquired through the years of teaching experience.

Since Shulman (1986a, 1986b, 1987) called attention to the importance of PCK, educational researchers have sought specifically to explain the PCK construct (see Carleson, 1999; Grossman, 1990; Magnusson et al., 1999). Yet, most of the attempts to define and understand PCK have been through the lens of the researcher. These explanations have resulted in limited representations that have ultimately failed to inform school reform efforts. According to Van Driel et al. (2001), these representations do not consider the teachers' perspectives on their existing knowledge, beliefs, and attitudes. If educational researchers hope to affect the learning processes of teachers, then there has to be a representation of PCK that accurately reflects teachers' perspectives. This study thus aims to understand PCK from the perspective of experienced secondary science teachers who serve as mentors to beginning science teachers.

Research Questions

The research questions that guided this study were:

1. What are the components of PCK that experienced secondary science teachers reveal in teaching science?
2. What are the specific elements within each component?
3. How do the teachers conceptualize PCK with the components and elements?

In the three research questions above, the experienced secondary science teachers to whom I refer are mentor teachers in the “Teachers as Mentors” program. In this program, mentor teachers share their expertise in science teaching with beginning teachers who struggle with various classroom problems. Research on the roles that mentor teachers play demonstrates why these teachers are good subjects for understanding PCK. Mentor teachers are expected to have a deep understanding of subject matter, as well as an ability to create multiple representations in relation to real teaching situations (Feiman-Nemser & Parker, 1990; Huling-Austin, 1992) and be able to connect that knowledge to diverse student populations in the context of teaching (Kennedy, 1991b). They should have broader knowledge of diverse student populations and greater skills in observing and interpreting their learning and in helping novice teachers learn to teach in accordance with national mathematics and sciences teaching standards (Austin & Fraser-Abder, 1995; Wang & Odell, 2002).

Therefore, it seemed appropriate to select mentor teachers for articulating teachers' perspectives of PCK. They have more opportunities to develop, elaborate, and reflect on their own expertise — particularly PCK— throughout the mentoring process than those who are not mentors. They are, thus, expected to have their own ways of representing the PCK that they have accumulated over many years of teaching experience.

Significance of the Study

This study will be of value to the field of secondary science teacher education in the following manners:

1. There is a dearth of in-depth qualitative studies that define PCK from the perspective of experienced science teachers. This study may encourage other researchers and teachers to find new ways to approach, investigate, and facilitate the growth of the PCK of science teachers.
2. The attempt to represent a construct of PCK through the experienced teachers' lens and the findings of this study will provide an empirical foundation for constructing more applicable guidelines for practicing teachers to use for developing their own expertise in teaching science.
3. Conceptualizing PCK from teachers' perspectives can help those in teacher education understand how to construct professional development programs that are conducive to the growth of PCK.

Limitations of the Study

It is known that employing qualitative methods in educational studies has its limitations. Of course, several limitations over the course of this study were recognized. One of the key limitations of the study relates to the nature of naturalistic qualitative inquiry. In this type of analysis, one may easily misinterpret reality by highlighting some data and devaluing other data. My personal background and the pre-perceptions about pedagogical content knowledge that I acquired during my review of the literature may have limited my interpretation of the data. I often encountered difficulty in my effort to package what I was seeing in the data into clearly marked categories or subcategories. Thus, it is important to recognize the alternative realities that I might have overlooked, and that some of the realities I reported here might have been misinterpreted despite conscious efforts to enhance the credibility of this study (Lincoln & Guba, 1985) by triangulating the findings from various data sources. I also conducted a "member check" process (Lincoln & Guba, 1985) to clarify and check the accuracy of my understanding of the data. In yet another effort to establish credibility, I shared my interpretations with knowledgeable people who reviewed and assisted in clarifying my interpretations.

Another limitation of this study relates to the case study research design. As Merriam (1998) pointed out, a case study represents a part instead of a whole. Since I dealt with a small number of teachers in specific grades and subjects, my findings may not be generalized to other cases. However, considering that the components and elements that emerged from the data analysis correspond, to some extent, to those in similar studies, the findings are certainly relevant to those who are involved in, particularly, science teacher education.

Another limitation of the study was the time constraint. The more time I spent on interviews and observations, the better I was able to capture teachers' perceptions of PCK. Despite all my efforts, I was only able to conduct three interviews and two classroom observations for this study. However, I attempted to reduce the likelihood of misinterpreting of the data by member checking with participants during the process of analyzing the data. Thus, I believe that the findings of this study accurately represent my interpretation based on the shared ideas with the participants in the study.

Overview of the Following Chapters

The next chapter, Chapter 2, includes a review of literature in areas related to this study. This chapter was divided to two main parts. The first part, an overview of teachers' knowledge base in general, provides a review of the research on a model of teachers' knowledge and a discussion of various models of teacher knowledge generated by several researchers. The second part, a variety of educational research on PCK, discusses the definitions and components of PCK across a number of earlier studies.

Chapter 3 details the research methods employed to carry out this inquiry. This chapter of methodology includes a description of the sample, as well as the different data sources utilized for each of the three research questions. Additionally, Chapter 3 includes a thorough description of the data analysis procedures and analytical strategies employed in this study.

Chapter 4 presents the individual case studies developed for each of the four participants included in the investigation. These case studies were constructed by synthesizing the different data sources utilized during the study. Additionally, this chapter also includes a within-case and cross-case analysis aimed at identifying recurrent themes and categories in the pedagogical knowledge of the four secondary science teachers who participated in this study.

Finally, Chapter 5 includes the discussion of the findings, conclusions, implications of the study, and the directions for future research.

Definition of Terms

To provide a common base of understanding in this study, the following definitions are included:

Knowledge base of teaching science: the body of understanding, knowledge, skills, and dispositions that a teacher needs to perform effectively in a given teaching situation for example, teaching middle school science to a class of sixth-grades in an urban school or teaching chemistry to a class of high school seniors in an elite private school.

Scientific literacy: the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity related area as well as specific types of abilities

Components: marking of a segment of data with a descriptive word

Elements: specific units within each component

Construct: structural representation formed by linking the relationship among categories that emerge from the data and by presenting dominance of each category

CHAPTER TWO

LITERATURE REVIEW

> As professionals, most of us are familiar with the literature in the field. Literature can be used as an analytic tool if we are careful to think about it in theoretical terms. Used in this way, the literature can provided a rich source of events to stimulating thinking about properties and for asking conceptual questions. It can furnish initial ideas to be used for theoretical sampling. (Strauss & Corbin, 1998, p. 47)

Overview

This chapter is a review of the literature related to the study. I will begin by discussing models of teachers' knowledge as conceptualized by several renowned researchers in the area and then moving on to a review of previous research on the knowledge of science teachers. A review of the literature on PCK (Pedagogical Content Knowledge) as a critical part of teachers' professional knowledge will follow, focusing on the nature, definition, and different conceptualizations of this concept.

Models of Teachers' Knowledge Bases

Before discussing the various models of teachers' knowledge base proposed by researchers, I would like to solidify the definition of "teachers' knowledge base". Adopting the definition of Wilson, Shulman, and Richert (1987), the term "teacher's knowledge base" is defined in this study as "the body of understanding, knowledge, skills, and dispositions that a teacher needs to perform effectively in a given teaching situation" (p.106); e.g., teaching middle school science to a class of sixth graders in an urban school, or teaching chemistry to a class of high school seniors in an elite private school. The attempt to understand the complexity of teachers' knowledge bases has generated a variety of conceptual models. I will draw an overview and discuss some of the seminal studies in this area from the past two decades.

In a case study with an English teacher, Elbaz (1983) used the term "practical knowledge" to refer to all kinds of knowledge integrated by the individual teacher in terms of personal values and beliefs oriented to her practical situation. In this effort, Elbaz called attention to the action and decision-oriented nature of the teacher's situation, which construes the teacher's knowledge as a function. Elbaz identified five categories of teachers' knowledge through five in-depth interviews in the study. The categories were: (1) knowledge of self, (2) knowledge of milieu of teaching, (3) knowledge of subject matter, (4) knowledge of curriculum development, and finally (5) knowledge of instruction (i.e. of students and of the teaching-learning process). "Knowledge of self" as a teacher encompasses three facets, including knowledge of self as a resource, knowledge of self in relation to others, and knowledge of self as an individual. The "knowledge of the milieu of teaching" represents teachers' understanding of how social settings interact with teachers' actions, such as in the classroom, relations with teachers and administrators, and the political milieu.

According to Elbaz's (1983) conceptualization of teachers' knowledge, "knowledge of subject matter" serves as the medium within which knowledge of milieu is shaped and knowledge of self is expressed. However, this area of knowledge is difficult to define because of "the constant and inevitable overlap between the subject matter itself, the actual skills being taught, and the view of learning which guides teaching" (p.58). This statement includes implicitly the concept of PCK within the knowledge area of subject matter.

Elbaz (1983) views these three areas of knowledge — knowledge of self, milieu, and subject matter — as static knowledge. Compared to those knowledge areas, 'knowledge of curriculum and instruction" relatively develop with teaching experience. The "knowledge of curriculum" represents the teachers' ability to identify a problem, determine students' needs, organize and develop materials, and evaluate students' learning. Finally, "knowledge of instruction" refers to a teacher's understanding of learning theory, students, the teaching process, and beliefs about teaching and organization of instruction. However, this study has been criticized for its truncated conceptualization of teacher knowledge, which emphasized the practical knowledge that teachers use while disregarding theoretical knowledge background.

In a comparative study of expert and novice mathematics teachers, Leinhardt and Smith (1985) examined the knowledge required for teaching. They argued that teaching draws upon two bodies of knowledge: knowledge of lesson structure and knowledge of subject matter. In the definition used by Leinhardt and Smith (1985), "knowledge of lesson structure" refers to "the skills needed to plan and run a lesson smoothly, to pass easily from one segment to another, and to explain material clearly" (p. 247). On the other hand, "subject matter knowledge" is topic specific. This area of knowledge involves, for elementary school mathematics teachers, "knowledge of the concepts, algorithmic operations, the connections among different algorithmic procedures, the subset of the number system being drawn upon, the understanding of classes of student errors, and curriculum presentation" (p.247). For Leinhardt & Smith, complete systems of subject matter knowledge for teaching include "multiple representations, understanding of basic arithmetic principles such as the identity function, and multiple linkages across concepts that are used in any one aspect of arithmetic" (p.269).

The concept of PCK is included implicitly in the category of subject matter knowledge. Although neither Elbaz's (1983) nor Leinhardt & Smith's (1985) work explicitly identified the concept of PCK as an individual category comprising teachers' knowledge bases, both studies served as a springboard for proposing the concept of PCK.

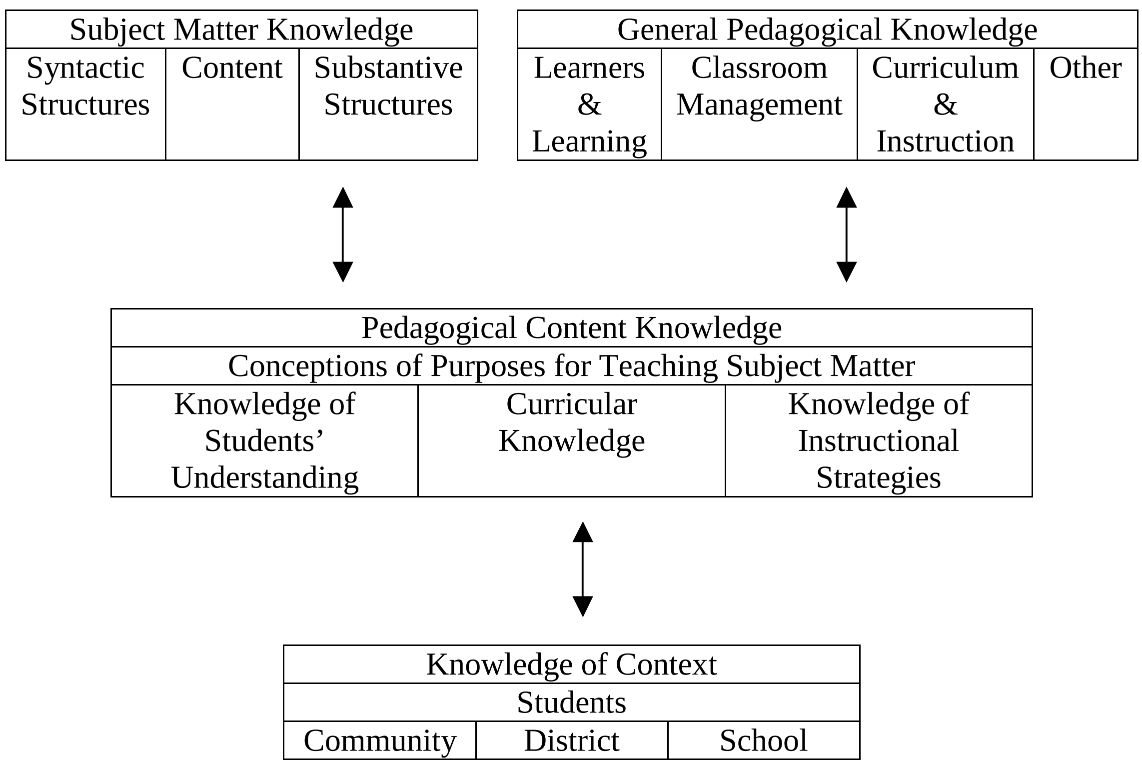
Researchers at Stanford University (Shulman, 1986b, 1987; Wilson, Shulman, & Richert, 1987) proposed a more comprehensive model of the professional knowledge base for teaching. According to the findings of the study, teachers draw upon many types of knowledge when making decisions in instructional planning and practice. Teachers use (1) knowledge of subject matter, (2) knowledge of curriculum, (3) knowledge of learners, (4) knowledge of educational aims, (5) knowledge of other content, (6) pedagogical content knowledge, and (7) general pedagogical knowledge.

Elaborating upon the concept of teachers' knowledge bases, these researchers called special attention to pedagogical content knowledge because this unique knowledge of a teacher — a blending of pedagogy and content — represents "an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8).

Grossman (1990) reviewed different definitions of "teachers' knowledge base" with various components and incorporated them into four general areas of teacher knowledge which can be seen as the cornerstones of the emerging work on professional knowledge for teaching: (1) general pedagogical knowledge; (2) subject matter knowledge; (3) pedagogical content knowledge; and (4) knowledge of context (see Figure 2).

In Grossman's (1990) model, "general pedagogical knowledge" includes knowledge and beliefs concerning learning and learners; knowledge of general principles of instruction; knowledge and skills related to classroom management; and knowledge and beliefs about the aims and purpose of education. "Subject matter knowledge" is composed of two elements: the content of the subject area and the knowledge of the structures of a subject. Grossman adopted Schwab's (1978) notion to elaborate the latter knowledge into "syntactic" and "substantive" structures. According to Schwab, the substantive structure includes the concepts, ideas, understandings, principles, and propositions that characterize the discipline. This structure influences the disciplinary perspectives of a researcher and the research questions he or she pursues. The syntactical structure refers to the methods researchers use to achieve their goals. Grossman agreed that subject matter knowledge influences heavily what and how teachers teach. Therefore, this knowledge is strongly related to teachers' PCK.

Figure 2. Grossman's model of teacher knowledge



Defining PCK as knowledge that is specific to teaching a particular subject matter, Grossman asserted that teachers must draw upon that knowledge to formulate "appropriate and provocative representations of the content to be learned" (p. 8). In Grossman's model, PCK is placed in the central part depending upon three other areas of knowledge — subject matter knowledge, general pedagogical knowledge, and knowledge of context. Lastly, "knowledge of context" is considered as one of the essential components of teachers' knowledge, allowing teachers to adapt to specific students and the demands of school districts.

Discussions of Science Teachers' Knowledge Bases

Since certain aspects of teachers' knowledge are discipline-dependent, it is necessary to review the efforts to theorize the knowledge base of science teachers. The following paragraphs provide an overview of the research literature related to models of teachers' knowledge bases that exists within the field of science education. Building upon Shulman's (1987) work, considerable efforts have been made to articulate science teachers' knowledge base, with some modification that includes the addition of other components.

With a focus on the training of biology teachers, Tamir (1988) attempted to reorganize and extend the categories suggested by Shulman's group into a general framework, which can be used as a foundation for teacher education. Six categories that encompass this framework are: (1) general liberal education; (2) personal performance; (3) subject matter; (4) general pedagogical; (5) subject matter specific pedagogical; and (6) foundations of the teaching profession. Tamir argued that the term "subject matter knowledge" is more reasonable than the term "content knowledge" because the knowledge accurately includes the content of a subject *per se*, as well as the structure and process of a given subject. In Tamir's conceptualization of teachers' knowledge bases, the notion of subject matter specific pedagogical knowledge is equivalent to that of PCK. The study suggested that three of those categories — subject matter knowledge, general pedagogical knowledge, and subject matter specific knowledge — could be dealt with in pre-service teacher education. Tamir (1988) was the only one to distinguish between knowledge (knowing that) and skills (knowing how) under each category in the framework of teachers' knowledge.

Signifying that what good teachers know, do, and feel is largely about teaching, and is situated in everyday classroom life, Barnett and Hudson (2001) suggested an exemplary science teachers' knowledge model called "pedagogical context knowledge", including four kinds of knowledge: (1) academic and research knowledge, (2) pedagogical content knowledge, (3) professional knowledge, and (4) classroom knowledge. In this model, "academic and research knowledge" refers to: (a) science content knowledge including concepts, facts, and theories; (b) knowledge about the nature of science, including issues in the history, philosophy, and sociology of science and the relationships among science, technology, society, and environment; and (c) knowledge about how and why students learn. "Professional knowledge" refers to the knowing of teaching by unconsciously-reflected experience including the political and sociological knowledge of schooling, as well as the professional knowledge of education. The last category, "classroom knowledge", is the knowledge that teachers have of their own classroom and students, which is entirely situational and specific to that teacher. Using this framework to analyze interviews with science teachers about the ways in which they design and implement science lessons, Barnett and Hudson (2001) asserted that this model of pedagogical context knowledge provides a simple and effective way of examining teachers' views and the knowledge on which they draw when they teach or talk about their teaching.

Carlsen (1999) reformulated science teachers' knowledge into five general categories: (1) knowledge about the general educational context including nation, state, community, and schools; (2) knowledge about the specific educational context, including the classroom and students to be taught; (3) general pedagogical knowledge; (4) subject matter knowledge, including syntactic and substantive structures of science, as well as the nature of science and technology; and (5) pedagogical content knowledge. In the attempt to explore teachers' knowledge from post-structural viewpoints, Carlsen (1999) explicated knowledge bases for teaching by adding subcategories that reflect recent developments in educational research and science education reform.

Looking at recent research on teachers' knowledge, it is clear that most researchers agreed upon seeing PCK as a crucial part of that knowledge, because it prompts teachers' pedagogical decisions and strategies with regard to presenting their subject matter to their students. In the following sections, literature pertaining to PCK — particularly focusing on the definition and nature — will be reviewed. Following that, different conceptualizations of PCK will be discussed.

Definitions of PCK

When classifying content knowledge into three categories — (1) subject matter knowledge; (2) curricular knowledge; and (3) PCK — Shulman (1986b) defined pedagogical content knowledge (PCK) as a knowledge which "goes beyond knowledge of the subject matter per se to the dimension of subject matter knowledge for teaching (p. 9). Since Shulman addressed PCK, many researchers in the area of teacher education have shone a spotlight on PCK as a critical category, which bestows uniqueness upon teachers as professionals. Despite numerous conceptualizations of PCK, Shulman's definition of this concept remains the standard. Thus, it is worth calling to mind Shulman's initial definitions of PCK before exploring teachers' conceptualizations of PCK

Shulman (1986b) identified pedagogical content knowledge (PCK) as "the most useful forms of content representation, the most powerful analogies, illustrations, examples, and demonstrations — in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (p. 9). That area of knowledge also includes "an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" (p.9).

Additional articles by Shulman and his colleagues further developed the conceptions of the domain of teacher knowledge and knowledge categories for teaching. PCK was placed by Shulman (1987) as one of seven categories of knowledge base for teaching, equally aligned with content knowledge, general pedagogical knowledge, curricular knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of the philosophical and historical aims of education. PCK was defined as:

> The special amalgam of content and pedagogy that is uniquely the providence of teachers, their own special form of professional understanding… Pedagogical content knowledge…identifies the distinctive bodies of knowledge for teaching. …Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue (Shulman, 1987, p.8).

The National Science Education Standards [NSES] (NRC, 1996) put great emphasis on developing the PCK of science teachers. NSES defined PCK as "special understandings and abilities that integrate teachers' knowledge of science content, curriculum, learning, teaching and students," which allows science teachers to "tailor learning situations to the needs of individuals and groups" (p. 62).

Although the concept of pedagogical content knowledge is still difficult to pin down theoretically, it is clear that this knowledge for science teaching represents a class of knowledge that is central to science teachers' work and that would not typically be held by scientists or by teachers who know little of science subject matter. Therefore, the working definition of PCK for this study is as follows: "PCK encompasses the knowledge and its applications that science teachers incorporate into their pedagogical action to facilitate students' better understanding of scientific concepts and to encourage students' scientific inquiry by using effective instructional strategies, representations, and assessment tools within diverse teaching situations." Within the foregoing definition, "scientific inquiry" refers to "the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1996, p. 23).

Nature of PCK

PCK has been characterized as an experiential knowledge because it is often thought to be developed through classroom experience (Baxter & Lederman, 1999; Gess-Newsome, 1999; Grossman, 1990; NRC, 1996; Magnusson et al., 1999; Van Driel et al., 2001). Therefore, it is understood that pre-service or beginning teachers usually have limited or minimal PCK. The PCK of expert science teachers involves an integrated understanding of teaching science through "trial and error in teaching situations, continual thoughtful reflection, interaction with peers, and much repetition of teaching science content" (NRC, 1996, p.67). In this aspect, collaborative work between experienced teachers and beginning teachers through professional development programs can be an effective way to foster the growth of PCK of beginning teachers. The deeper PCK base in science teaching held by experienced teachers is closely related to interaction in the collaborative work; through the process of interaction, such a knowledge base provides the foundation and context that helps beginning teachers to develop their own expertise (Wang & Odell, 2002).

Pre-service courses can initiate the development of PCK in science teachers, and so teacher educators need to make a concerted effort to build such knowledge. In order to do this, pre-service science teachers need to be aware of the methods and strategies in science education, and have opportunities to learn about science.

Furthermore, this should occur during the field experience portion of a teacher education program, as well as at the university. PCK is a “transformative” construct, since content and pedagogy are integrated and transformed into classroom practice (Gess-Newsome, 1999).

Gess-Newsome (1999) presents two models for pedagogical content knowledge: the integrative and transformative model. The comparative overview of these two models is presented in Table 1. To make a distinction between the two models, a “mixture versus compound” analogy was used. In the integrative model, the knowledge domains of subject matter, pedagogy, and context tend to exist as separate entities, like chemical elements in a mixture. On the other hand, PCK in the transformative model is recognized as a synthesized knowledge base for teaching, as in a chemical compound.

For beginning teachers the integrative model is more appropriate, since beginning teachers tend to rely more heavily on one domain of knowledge rather than drawing simultaneously from all domains, as is the case with an expert teacher (Gess-Newsome, 1999). My interpretation is that a variety of conceptualizations of PCK come from these two different viewpoints. With its description of PCK as comprising two primary components — knowledge of (1) students and (2) instructional strategies and representations — Shulman’s notion of PCK might be equivalent to that of the integrative model. Meanwhile, as other researchers acknowledged PCK as being essentially a transformative model, they expanded the concept of PCK adding other components, including knowledge of subject matter, curriculum, purpose, context, and assessment to the original two components. Since it is hard to draw a distinct line between these two models, however, it may be useful to place PCK on a continuum of models of teacher knowledge, with the integration model at one end and the transformative model at the other end.

Marks (1990) discussed the development of PCK as an integrative process revolving around the interpretation of subject-matter knowledge and the specification of general pedagogical knowledge. Marks also asserted that it is impossible to distinguish PCK from either subject matter knowledge or general pedagogical knowledge. Also viewing PCK as integrated knowledge, Fernandez-Balboa and Stiehl (1995) suggested that enhancing any of the components would enhance PCK as a whole.

Although conceptualizations of PCK varied greatly, the researchers came to a consensus on the nature of PCK, which is twofold: (1) PCK is the experiential knowledge and skills that are acquired through the classroom experience (Grossman, 1990; NRC, 1996; Baxer & Lederman, 1999; Gess-Newsome, 1999; Magnusson et al., 1999; Van Driel et al., 2001), and (2) PCK is the integrated set of knowledge, concepts, beliefs, and values which teachers develop in the context of the teaching situation (Marks, 1990; Ferdandez-Balboa and Stiehl, 1995; Van Driel et al., 1998; Gess-Newsome, 1999; Loughran et al., 2001; 2004).

Table 1. Overview of Integrative and Transformative models of teacher knowledge (Gess-Newsome, 1999, p. 13)

	Integrative Model	Transformative Model
Knowledge domains	Knowledge of subject matter, pedagogy, and context are developed separately and integrated in the act of teaching. Each knowledge base must be well structured and easily accessible.	Knowledge of subject matter, pedagogy, and context, whether developed separately or integratively, are transformed into PCK, the knowledge base used for teaching. PCK must be well structured and easily accessible.
Teaching Expertise	Teachers are fluid in the active integration of knowledge bases for each topic taught.	Teachers possess PCK for all topics taught.
Implications for Teacher Preparation	Knowledge bases can be taught separate or integrated. Integration skills must be fostered. Teaching experience and reflection reinforces the development, selection, integration, and use of the knowledge bases.	Knowledge bases are best taught in an integrated fashion. Teaching experience reinforces the development, selection, and use of PCK.
Implications for Research	Identify teacher preparation programs that are effective. How can transfer and integration of knowledge best be fostered?	Identify exemplars of PCK and their conditions for use. How can these examples and selection criteria best be taught?

In the effort to illuminate PCK through secondary science teachers' perspectives in the present study, my view, in alignment with several researchers' views of PCK, is that PCK is the result of a transformation of knowledge of content (subject matter), pedagogy, and context. Given that participating teachers have more than 10 years of teaching experience, their conceptualization of teachers' knowledge that emerged from interviews and classroom observations is likely to represent their own PCK as a transformative knowledge acquired and shaped by classroom experience. Therefore, it is reasonable to assume that attempting to re-conceptualize PCK from experienced science teachers' perspectives can provide a more appropriate, relevant guideline for science teachers' professional development, particularly with regard to PCK.

Different Conceptualizations of PCK

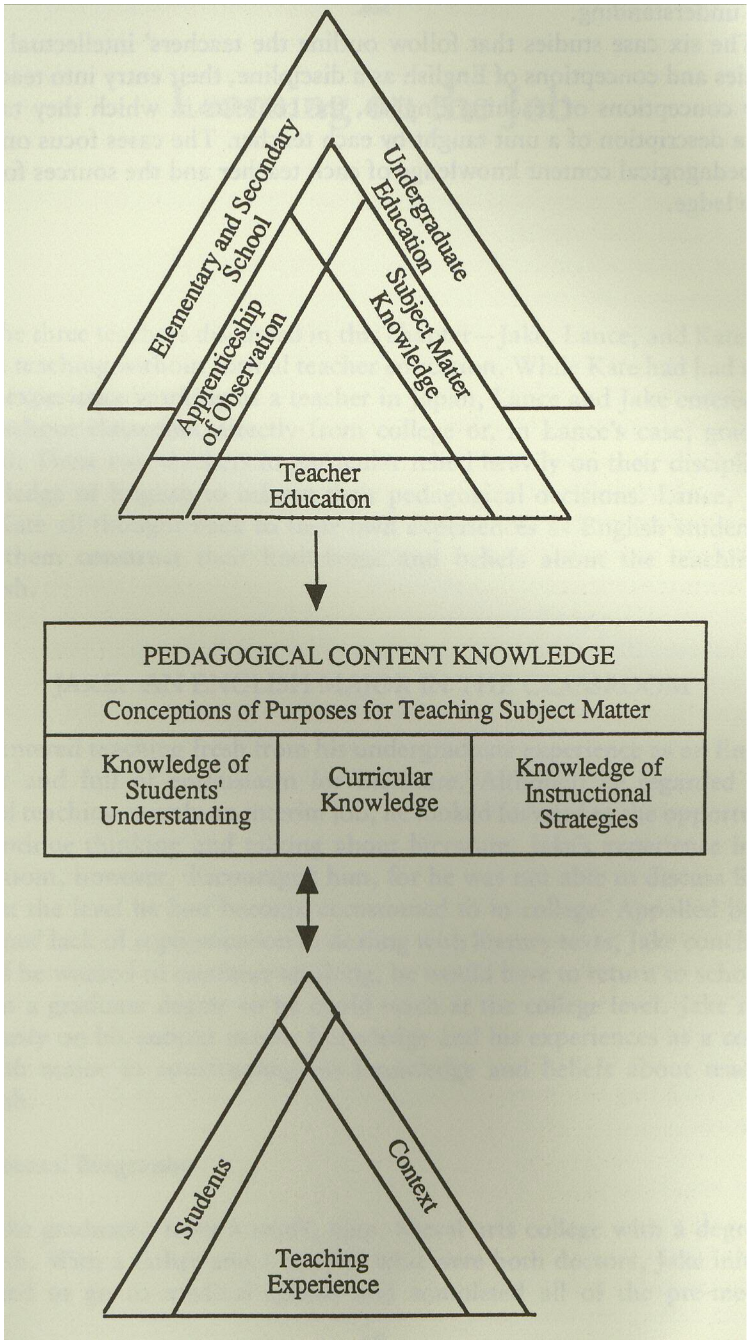
Since the introduction of the concept of pedagogical content knowledge (PCK), educational researchers have attempted to describe and understand the PCK of teachers. However, accounts of PCK and attempts to measure it have varied greatly. Table 2 summarizes different conceptualizations of PCK by different researchers.

Elaborating on teachers' knowledge base, Shulman (1986b, 1987) identified initially two key components of PCK. The first category is knowledge of comprehensive representations of subject matter, which indicates the ways of representing and formulating the subject that makes it comprehensible to others. Powerful analogies, illustrations, explanations, and demonstrations fall into this category. The second category is a teacher's understanding of content-related learning difficulties. Knowing students' preconceptions — and which of those are misconceptions — a teacher can properly use knowledge of the strategies to reorganize the learners' understanding.

Many researchers of PCK since Shulman have extended the concept by adding other categories, which are distinct in Shulman's knowledge base for teaching. As discussed in the previous section, PCK can be interpreted as being either integrative or transformative, according to researchers' viewpoints of that knowledge. Before examining experienced secondary science teachers' conceptualizations of PCK in the present study, it is necessary to review, in depth, the previous literature in the area. The following paragraphs describe in chronological order, a variety of conceptualization of PCK by different researchers.

In an attempt to refine Shulman's work, Grossman (1990) developed an expanded definition of PCK that included four central components: (1) conceptions of purposes for teaching subject matter; (2) knowledge of students' understanding; (3) curricular knowledge; and (4) knowledge of instructional strategies. With this framework she then examined the influence of teacher education on teachers' knowledge growth. Grossman (1990) also identified four possible sources of PCK: (1) apprenticeship of observation; (2) subject matter knowledge that influences personal preferences for specific purposes or topics; (3) specific courses during teacher education; and (4) classroom teaching experience. Figure 3 illustrates how these sources affect teachers' PCK. According to Grossman's notion, teachers rely on their apprenticeships of observation, their disciplinary backgrounds, and professional education in constructing their PCK. Teaching experience also directly affects the development and refinement of that knowledge.

Figure 3. Conceptual framework of four possible sources of PCK



Marks (1990) also expanded Sulman's notion of PCK through a study that was designed to present PCK in mathematics which was constructed from interviews with fifth-grade teachers. Analysis of the interviews resulted in extended conceptualization of PCK consisting of four main components: (1) subject matter for instructional purposes; (2) students' understanding of the subject matter; (3) media for instruction in the subject matter (i.e., texts and materials); and (4) instructional processes for the subject matter. Marks asserted that these components are highly interconnected, rather than existing individual elements. One of the most interesting points in his conceptualization of PCK is that he draws attention to media used as a tool and resource for instruction. Another distinct point of his model is that the area of instructional processes is described extensively and consists of three domains: student focus, presentation focus, and media focus. This component is an expanded version of the "'knowledge of comprehensive representations of subject matter" that identified by Shulman (1987).

Based on an explicit constructivist view of teaching, Cochran, DeRuiter, and King(1993) renamed PCK as "pedagogical content knowing" (PCKg) to acknowledge the dynamic nature of knowledge development. In their model, PCKg is conceptualized more broadly than Shulman's view. PCKg is defined as "a teacher's integral understanding of four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning" (Cochran et al., 1993, p. 266).

Table 2. Different conceptualizations of PCK

	Knowledge of:							
Scholars	Subject matter	Representations and instructional strategies	Student Learning and conceptions	General Pedagogy	Curriculum and Media	Context	Purposes	Assessment
Shulman (1987)	a	PCK	PCK	a	a	a	a	b
Tamir (1988)	a	PCK	PCK	a	PCK	b	b	PCK
Grossman (1990)	a	PCK	PCK	a	PCK	a	PCK	b
Marks (1990)	PCK[1]	PCK	PCK	b	PCK	b	b	b
Cochran, et al. (1993)	PCKg[2]	b	PCKg	PCKg	b	PCKg	b	b
Fernandez-Balboa & Stiehl (1995)	PCK	PCK	PCK	b	b	PCK	PCK	b
Magnusson, Krajcik, and Borko (1999)	a	PCK	PCK	a	PCK	a	PCK	PCK
Carlsen (1999)	a	PCK	PCK	a	PCK	a	PCK	b
Loughran et al. (2001)	b	PCK	PCK	b	PCK	b	PCK	PCK

[1] PCK: Pedagogical Content Knowledge a: distinct category in the knowledge base for teaching
[2] PCKg: Pedagogical Content Knowing b: not discussed explicitly

Exploring how university professors construct and implement generic PCK across several fields, Fernandez-Balboa and Stiehl (1995) drew distinctions between two types of PCK: “specific” PCK, which is particular to the instruction of a specific subject or content area; and “generic” PCK, which is common to instruction across all subjects or content areas. Based on the data obtained from interviews with 10 university professors, they identified five components of effective professors’ generic PCK: knowledge about (1) the subject matter, (2) the students, (3) numerous instructional strategies, (4) the teaching context, and (5) one’s teaching purposes.

In the area of science education, there have been attempts to conceptualize the PCK of science teachers by Carlsen (1999); Loughran et al.(2004); Magnusson, Krajcik and Borko (1999); and Tamir (1988). With an extended framework for reorganizing teachers’ knowledge, Tamir (1988) conceptualized PCK in the name of “subject matter specific pedagogical knowledge,” which is comprised of four components: students, curriculum, instruction, and evaluation. Tamir asserted that PCK is a unique area of knowledge handled by instructors who are pedagogical experts in a particular discipline working with student teachers preparing to teach in that discipline. He dichotomized each component into two elements: knowledge and skill. While “knowledge” refers to “propositional knowledge (knowing that),” “skill” refers to “procedural knowledge (knowing how).” (p. 100) Focusing on the training of pre-service biology teachers at college, each category of the framework is explained in detail using specific examples related to the discipline of biology. Given that Tamir’s work is based on the evidence from actual courses in pre-service teacher education, this framework seems to provide a more comprehensive guideline for understanding and developing PCK. Figure 4 presents Tamir's conceptualization of PCK and examples of each element of subject matter-specific pedagogical knowledge.

Figure 4. Tamir's conceptualization of PCK

1. Student
   - 1.a. Knowledge: Specific common conceptions and misconceptions in a given topic
   - 1.b. Skills: How to diagnose a student conceptual difficulty
2. Curriculum: How to diagnose a student conceptual difficulty in a given topic
   - 2.a. Knowledge: The pre-requisite concepts needed for understanding photosynthesis
   - 2.b. Skills: How to design an inquiry oriented laboratory lesson
3. Instruction (Teaching and management)
   - 3.a. Knowledge: A laboratory lesson consists of three phases: pre-lab discussion, performance, post –laboratory discussion
   - 3.b. Skills: How to teach students to use a microscope
4. Evaluation
   - 4.a. Knowledge: The nature and composition of the Practical Tests Assessment Inventory
   - 4.b. Skills: How to evaluate manipulation laboratory skills

Magnusson, Krajcik and Borko (1999) conceptualized pedagogical content knowledge to be composed of five components. The first component refers to orientations toward science teaching, which represent the general ways of viewing science teaching. The second component relates to one's knowledge and beliefs about the science curriculum, including goals, objectives, specific curricular programs and materials. Knowledge and beliefs about the students' understanding of specific science topics is the third component, which includes students' difficulties and misconceptions associated with specific science concepts. The fourth component consists of a teacher's knowledge and beliefs about assessment in science, and the last component refers to the knowledge and instructional strategies for teaching science, including both subject-specific and topic-specific strategies.

Defining PCK as different from, but related to, "general pedagogical knowledge" and "subject matter knowledge," Carlsen (1999) conceptualized PCK with four components: (1) students' common misconceptions, (2) topic-specific instructional strategies, (3) specific science curricula, and (4) purposes for teaching science. Particularly, he emphasized the first two components with special significance to science education. Carlsen also described topic-specific instructional strategies as "knowledge that science teachers draw upon in choosing and using models, orchestrating substantive classroom discourse, and managing laboratory activities" (p.141).

Meanwhile, in the attempt to understand and portray science teachers' PCK with CoRe (Content Representation) and PaP-eRs (Professional and Pedagogical experience Repertoire) approaches, Loughran, Mulhall, Berry (2004) considered five aspects of PCK: (1) approaches to the framing of ideas and effective sequencing; (2)

knowledge of students; (3) insightful ways of testing for understanding; (4) knowledge of difficulties and limitations connected with teaching; and (5) knowledge of alternative conceptions. Including these components, Loughran et al. (2004) developed the CoRe matrix of eight questions — which include those five components of PCK — to codify teachers' PCK related to a specific content. The eight questions used to visualize teachers' PCK were as follows:

1. What do you intend for the students to learn about this idea?
2. Why it is important for students to know this?
3. What else do you know about this idea that you do not intend students to know yet?
4. What difficulties/limitations are connected with teaching this idea?
5. What knowledge about students' thinking influences your teaching of this idea?
6. What other factors influence your teaching of this idea?
7. What are the teaching procedures and particular reasons for using these to engage students with this idea?
8. What specific ways of ascertaining students' understanding or confusion around this idea will you use?

Loughran et al.'s (2004) CoRe questions were adapted for the second interview in the present study. This method was suggested as "a way of collecting science teachers' PCK and portraying it in an articulable and documentable form" (p. 381). The interview data related to these questions will be discussed in Chapter 4.

Summary

Although there is prolific research on PCK, it is interesting to note that there is no universally accepted conceptualization of it. In an effort to make sense of this complexity by reviewing the literature on PCK, I have identified four components of PCK that are commonly found in various conceptualizations of PCK. Most researchers recognize the following four components as essential parts of PCK: the knowledge of students' understanding, instructional strategies and representations, curriculum, and purposes. Are these four categories, defined in common by researchers in this discipline, the same ones which science teachers perceive to be their unique professional knowledge domains? The goal of this study is to examine what components emerge from experienced secondary science teachers' perspectives and how those teachers conceptualize those components in a construct for representing science teachers' PCK. I will compare the common four components of PCK with the components which emerged from this study, and discuss in-depth the implications of the findings in Chapter 4.

CHAPTER THREE

RESEARCH METHODS

> Discovery has been the aim of science since the dawn of the Renaissance. But how those discoveries are made has varied with the nature of the materials being studied and the times… Although we are studying object more worldly than, yet often just as elusive as, the sun and the stars, we, like Galileo, believe that we have an effective methods for discovery. (Strauss & Corbin, 1998, p. 1)

Overview

This chapter will discuss the methods of inquiry, data collection and analysis for this qualitative research study. Case study design was adopted in order to reveal the perception of PCK of secondary science teachers while grounded theory was utilized as the analytic framework. As the qualitative researcher is “the primary instrument” for data collection and analysis (Merriam, 1998), I have also included a description of my background as researcher in this study. Purposeful sampling was used to select participants for the study and the criteria and process for selecting the five participants will be discussed. The data collection process and the primary data sources, including interviews and classroom observations, will be discussed in detail. The data analysis will be described including the process and explanation of the use of NVivo 2.0 as an analytic tool. Finally, the design of the research will be compared to established criteria relating to validity.

Research Design: A Case Study Method

A case study method is utilized to conduct an in-depth investigation of how mentor science teachers perceive pedagogical content knowledge and how they conceptualize their own PCK with regard to their teaching practice. According to Merriam (1998), this research method is the best vehicle for providing "intensive descriptions and analyses of a single unit or bounded system such as an individual, program, or group" (p. 19). By employing case study methods, I intended to present an in-depth understanding of the situation and meaning for those involved.

Merriam (1998) states that the case study is particularistic. "Particularistic" is defined as focusing on "on a particular situation, event, program, or phenomenon" (p.29). This research is particularistic, in that the participants were selected from a mentoring program called "Teachers as Mentors," hosted by Our Lady of the Lake University in San Antonio, Texas. Within the context of mentoring, participating teachers are asked to reveal their own particular understanding of PCK.

Research on the roles that mentor teachers play demonstrates why these teachers are good subjects for understanding PCK. Mentor teachers are expected to have a deeper understanding of the subject matter as well as how it is taught in real teaching situations (Feiman-Nemser & Parker, 1990; Huling-Austin, 1992). It is reasonable to expect mentor teachers to be able to impact that knowledge to diverse student populations in the classroom (Kennedy, 1991b). They should have a broader knowledge of diverse student populations and greater skills in observing and interpreting how well they are learning as well as assisting novice teachers to teach according to national mathematics and sciences teaching standards (Austin & Fraser-Abder, 1995; Wang & Odell, 2002). Therefore, it seemed appropriate to select mentor teachers for articulating teachers' perspectives of PCK. They have more opportunities to develop, elaborate, and reflect on their own expertise — particularly PCK— throughout the mentoring process than those who are not mentors. They may have their own ways of representing PCK that they have developed and accumulated due to many years of teaching experience.

Another characteristic of the case study is to be descriptive because a case study pursues "a rich and thick description of the phenomenon under study" (Merriam, 1998, p.29). Given the descriptive characteristic of the case study, I will enclose a general description of each participant's background and teaching context in the following chapter, in which I will also discuss the findings of this study. I will also illuminate, in detail, specific categories and subcategories which have emerged from the interviews and class observations for each participating teacher, linking each to their teaching experience and environment. This effort will allow me to share with the reader a rich description of the components that emerged from data of each participant prior to offering their conceptualizations of it.

Analytic Framework: Grounded Theory

Grounded theory methodology is used as the analytic framework for this study. The primary goal of grounded theory is to generate theory inductively from collected data (Glaser and Strauss, 1967). I drew upon the techniques and procedures developed by Strauss and Corbin (1998) to develop the grounded theory analytic framework for this study. In the discussion of grounded theory methods, it may be helpful to first define theory. Strauss and Corbin (1998) define theory in the following way: "Theory denotes a set of well-developed categories (e.g., themes, concepts) that are systematically interrelated through statements of relationship to form a theoretical framework that explains some relevant social, psychological, education, nursing, or other phenomenon" (p.22). In accordance with this definition, the main goal of this study is to identify themes that indicate the domains of PCK defined by participating science teachers, and to build a theory that represents a conceptualization of PCK from the perspective of these science teachers.

In grounded theory, three types of coding are involved in the process of data analysis (Strauss and Corbin, 1998):

- Open coding: the analytic process through which concepts are identified and their properties and dimensions are discovered in data (p. 101);
- Axial coding: the process of relating categories to their subcategories, termed "axial" because coding occurs around the axis of a category, linking categories at the level of properties and dimensions (p. 123); and
- Selective coding: the process of integrating and refining the theory (p. 143)

The data analysis for this study drew upon these three types of coding as procedures for finding a theory, as defined earlier in this section. Detailed descriptions of the specific processes will be provided in the data analysis section of this chapter. The categories and theories that emerged from this study will be discussed at length in Chapter 4.

Researcher Background

In attempting to articulate the teacher's perspective of PCK, of course, it is inevitable that I, as a researcher should bring to the study my own perspective. This perspective — derived from my own experience of teaching as well as theoretical sources — generated the basic assumption that guided the study. That basic assumption, of course, is simply that practical knowledge of teachers exists, and this knowledge is experientially acquired. The characteristics and criteria of this knowledge can thus be defined through a direct examination of the thinking of teachers at work. This statement implies both a particular way of speaking about teachers' knowledge and a methodological commitment to a particular way of studying that knowledge.

For a significant part of my professional career, I taught middle school science and high school earth science in an urban area in Korea. As a middle school teacher, I taught general science and biology to seventh through ninth grade students for four years. As a high school teacher, I taught earth science and general science to tenth through twelfth grade students in an urban school with a population of approximately 2000 students. During my years of teaching, I struggled with being a good science teacher. Since I double-majored in Geology and Science Education at college, I was pretty confident with my knowledge of science content. However, I learned over the years of teaching — both in middle school and high school — that *teaching* science was different from *knowing* science. Following a desire to be more knowledgeable in science education and to be a science teacher educator, I decided to pursue graduate work in the United States, which led me to The University of Texas at Austin.

A considerable amount of my work in graduate school has been with the Texas Regional Collaboratives for Excellence in Science Teaching (TRC). This program is a statewide network of K-16 partnerships that provides sustained and high intensity professional development to K-12 teachers of science. My role in this program has involved both evaluation and research. I was responsible for collecting and analyzing data pertaining to the impact of the program on the practices of participating teachers. My research interest emerged from work in TRC as a graduate research assistant. During one of our meetings, a teacher asked me about pedagogical content knowledge (PCK). We spoke about this concept, and I ultimately decided this would be an area worth deeper investigation. Two years ago I began a study of the PCK of mentor teachers.

A significant amount of my time in the last year has been devoted to conceptualizing PCK from the perspective of experienced secondary science teachers. The concept of PCK is difficult to describe because there appears to be no particular best practice in science teaching. Thus, I believe that this study would be valuable in its attempt to reveal how good science teachers perceive their instructional knowledge.

Sampling

The participants in this study were recruited from a mentoring program hosted by Our Lady of the Lake University in San Antonio. “Teachers as Mentors” is an in-service teacher professional development program designed to enhance beginning teachers’ PCK and skills through the mentoring process. The purpose of the Teachers as Mentors program is to train master science teachers to be mentors and thus provide support to induction year teachers. This mentoring program includes a cohort of 30 teachers who will serve as mentors for 90 novice teachers during their induction year for South Central Texas school district. Through this mentoring program, experienced mentor teachers play a role in facilitating beginning teachers’ development as professionals, and they also have a chance to revitalize themselves by enhancing their own teaching and leadership skills.

Mentor teachers and program personnel in the “Teachers as Mentors” program were invited to participate voluntarily in this study via electronic mail. Mentor science teachers in the “Teachers as Mentors” program — who must have more than ten years of teaching experience and more than three years of mentoring experience— were eligible for this study. Participation was open to all eligible teachers in the program regardless of age, gender, and ethnicity.

Initially, I asked the project director to identify a list of eligible teachers in the program and I contacted them individually via email. After many email exchanges encouraging participation, five secondary science teachers (with more than ten years of teaching experience and three years of mentor experience) were finally selected for semi-structured, one-on-one interviews and classroom observations (Table 3). The following is a brief description of each participant's background:

1. Wendy has 28 years of teaching experience in high school and is currently teaching Chemistry, Physics, and advanced placement Biology. She has a bachelor's degree in Kinesiology and Biology and a master's in Biology and Integrated Science. She is actively engaged in this mentoring program and participating enthusiastically in many workshops for science teachers.
2. Shawna has 32 years of teaching experience and is currently teaching sixth grade science in a public school. As an undergraduate, she earned a degree in Elementary Education and returned to college for Certification in Secondary Science teaching. She also has a master's degree in Education Administration. She serves as a mentor of the mentor teachers in the program.
3. Roger, the only male participant in the present study, teaches Integrated Physics and Chemistry (IPC) and Geology, Meteorology, and Oceanography (GMO) in high school. He has ten years of teaching experience.
4. Emily has 16 years of experience teaching sixth and seventh grade science as a certified public school science teacher. She has a bachelor's degree in Biology and Chemistry and a master's degree in Integrated Science. She worked in middle school when I began to interview her and moved to high school one year after that. She is currently working as a high school science teacher.

Table 3. Participants demographic information

Participant	Teaching Years	Degree	Teaching Subjects	
Wendy	Total 28 years of teaching in high school (Kinesiology, PE, Biology, coach, 5 years; Physical Science, Biology, Marine science, 11years; Chemistry, AP Chem., AP Biology, Physical Science, GMO, 11 years)	Bachelor's in Kinesiology and Biology Master's in Biology and Integrated Science	10^{th} – 12^{th} grade Chemistry, Physics, AP Biology	Certified teacher Public school
Shawna	33 year teaching career (1-6^{th} grade , 8 years in middle school)	Bachelor's in Elementary Education Master's in Education Administration	6^{th} grade science	Certified teacher Public school
Roger	10 years	Bachelor's in Biology Master's in Education	9^{th} – 10^{th} grade - IPC 11^{th} –12^{th} grade – GMO (elective course)	Certified teacher (Composite science certification) Public school
Emily	11 years in middle school + 2 years in high school + 5 years in special ed.	Bachelor's in Biology & Chemistry Master's in Integrated Science	10^{th} -11^{th} Chemistry 6^{th} grade science 7^{th} grade science + 1 resource & ESL students	Certified teacher Public school

Data Collection

Schedule and Procedures

The invited participants (teachers and program personnel) received a study description that included the purpose of the study and explained the possible risks and benefits of participation. Teachers who were interested in participating in the study were asked to submit their contact information, such as telephone numbers and email addresses. A consent form was sent electronically to these participants for further review. Participants were also given tentative interview schedules. The interview schedules were flexible, according to the availability of the participant. A specific timeline is shown in Figure 5. (Also see Appendix A for detailed research timeline.)

The research aspect of this study is limited to examining the components of PCK and the specific elements within each component, based on the data from the four secondary science teachers who mentored beginning teachers. Data were generated for each participant in the following ways: three semi-structured interviews, two classroom observations, a collection of lesson plans, and monthly reflective summaries of participating teachers. Interviews were conducted on the days, times, and locations mutually agreed upon by the P.I. and study participants. Each participant was interviewed three times between November 1, 2003, and March 23, 2005. The first two interviews lasted no more than one to one and half hours, while the third interview took more than two hours for each participant. The interview protocols are attached in Appendix D, E, and F.

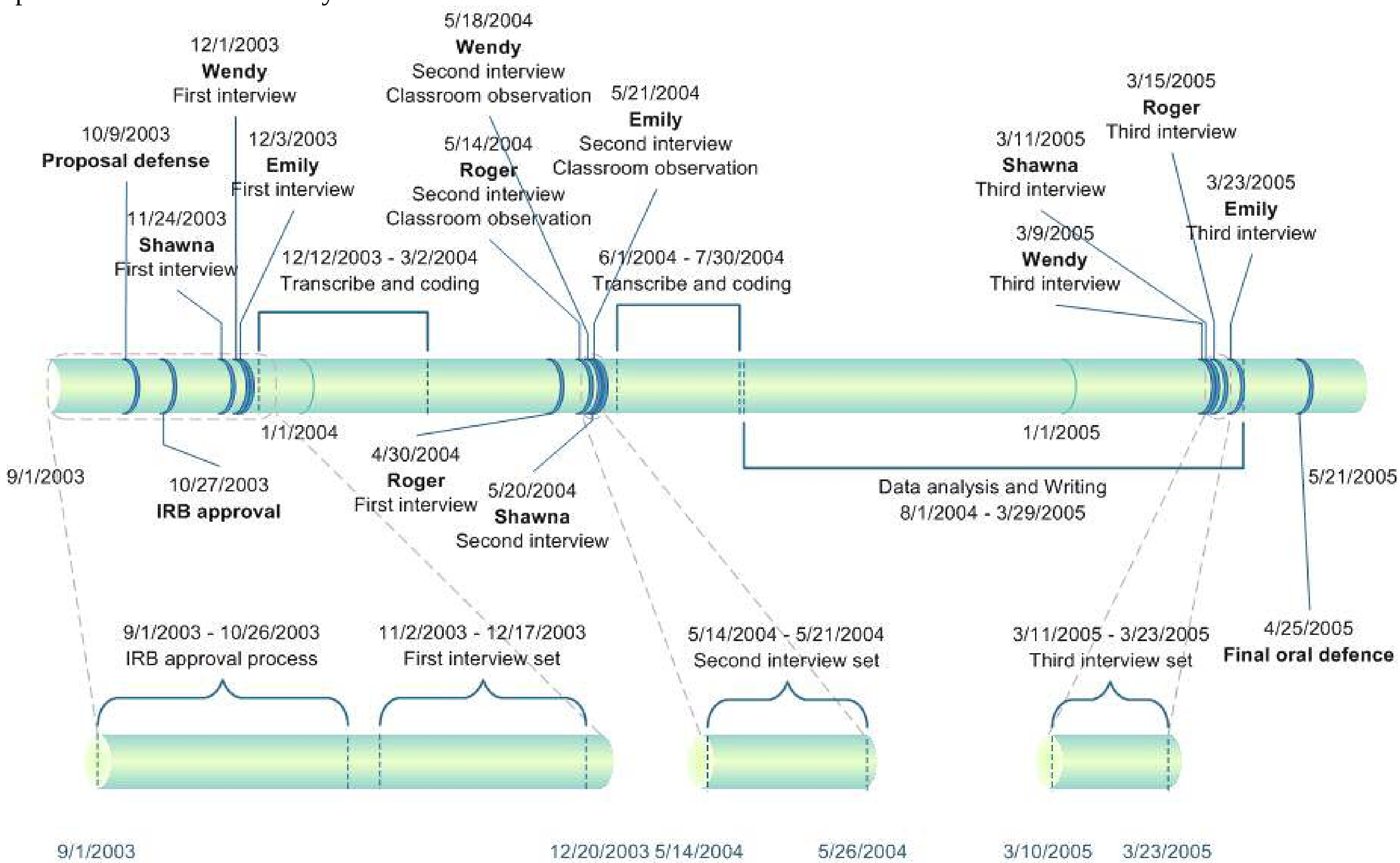
Given that schools in Texas tend to focus on TAKS — the statewide test — throughout the Spring semester, classroom observations were conducted during the Fall semester of 2004. Relevant documents (e.g., syllabi, lesson plans, handouts, monthly reflective summaries) were requested to supplement interview data. Monthly reflective summaries of participating teachers were utilized to better understand their perceptions of PCK.

Informed Consent

After getting a list of possible participants in this study from the “Teachers as Mentors” project director, I contacted them individually by email. In the email, I included an online-form that allowed the participants to fill out their biographical information (see Appendix for the on-line form). I then met individually with each participant who indicated an interest in participating in the study. I explained the purpose of the study and the required time commitment. All seven teachers agreed to participate in the study and signed the Informed Consent Form (see Appendix B for the Informed Consent Form). At the request of the Internal Review Board, the Teachers as Mentors project director needed to give informed consent, as the research was taking place with the mentor teachers in the program (see Appendix C for the Informed Consent Form).

As the study proceeded, three of the participants who agreed to the study were dropped from the study — one after the first interview, two after the second interview. The reasons for their withdrawal were time constraints and the discomfort they felt at classroom observations. Therefore, the results of this study report based on the remaining four participants’ data.

Figure 5. Specific timeline of the study



Data Description

There were three data sources: (1) interviews with mentor teachers and the program personnel, (2) class observations, and (3) supplementary documents (e.g., handouts, lesson plans, and reflective summary). Data from each source in this study were complementary and helped me obtain a holistic picture of teachers' conceptualization of pedagogical content knowledge. The data sources complement each other in the following manner.

Interview

The main data source was interviews. The interview set consists of three individual interviews for each participant. Merriam (1998) classifies interviews by the degree of structure present. She presented a continuum from highly structured/standardized to semi-structured to unstructured /informal (p.73). The interviews that I conducted fell on the continuum between highly structured/ standardized to semi-structured. For my interview protocols, I did prepare a list of questions that I developed based on discussions between my supervisor and myself. The interview protocol served as a tool to enable me to visualize their internal conceptualization. For each participant, the interview data was transcribed. The transcribed data were analyzed and coded prior to the next interview.

In addition, interviews with program personnel helped me understand the purpose of the mentoring program and mentoring activities, as well as their expectations of the program.

As I began to identify categories after the first interview, I was able to generate a list of additional questions to refine emerging categories. Through the interviews with participants, I expected to obtain the following information:

1. The nature and components of pedagogical content knowledge (PCK) within the context of teaching science, and
2. Their conceptualizations of PCK as an integrated knowledge area for teaching science.

In the first interview, biographical information was collected (see Appendix D for the first interview protocol).The second interview had two purposes: one was to further explore the knowledge components required to teach science, and the other was to clarify the observed teaching practice during classroom observations (see Appendix E for the second interview protocol). The third interview was conducted to provide participants with an opportunity to reflect on the results of the data analysis (see Appendix F for the third interview protocol). The participants were also asked to rate each component according to its importance in teaching science and to draw a concept map to represent their interrelationships.

Classroom Observations

Classroom observations were another data source for this study. By observing the participants teaching in their own classrooms, I was able to gain a better understanding of their teaching practices and the context in which they taught. And also, classroom observation also served as a source of interview questions. In the second interview, participants were asked to describe various activities observed during the classroom observations. Participants were asked not to make any changes in their teaching because of my being there. Certainly my presence in their classroom had some effect on their teaching, and more extensive classroom observations may have helped to address that concern.

Each participant was observed a minimum of two class periods for each class they taught. I arrived five to ten minutes prior to the start of the class period. Since I choose to take the role of classroom observer rather than participant, I usually sat in the back of the classroom. This decision enabled me to keep more detailed field notes. By actually observing teachers' classroom practice and taking field notes, I was able to capture the details of how teachers act in their classrooms with respect to PCK.

Supplementary Materials

I also collected lesson plans, project flyers, and monthly reflective summaries from each participant. From a collection of these supplementary materials, I was able to understand how PCK is represented in their lesson plans. In addition, examining the mentor teachers' monthly reflective summaries helped me to understand how the teachers' conceptions of PCK emerge from their own reflections and how they utilize those conceptions of PCK in their mentoring practices.

Data Analysis

The major unit of analysis was interview transcripts. I also considered field notes that I took during classroom observations, lesson plans for the observed classes and reflective summaries collected as a requirement for the mentoring as significant units, in addition to their interviews. Data analysis was based on the following process. Codes were formulated from the data in process and modified as the data collection proceeded. Given that qualitative research is an open-ended and on-going process, once analysis of the collected data began, the procedures continued to move recursively through the process of constant-comparative analysis (Lincoln & Guba, 1985; Patton, 2002). In other words, it was difficult to separate analysis from interpretation because the two procedures were interwoven. Moreover, the data analysis of each interview provided a foundation for developing subsequent interview questions.

Three types of coding, as mentioned earlier, were sequentially conducted to analyze the data: open coding, axial coding, and selective coding (Strause and Corbin, 1998). In the following paragraphs, each coding procedure will be described in detail. The graphic shown in Fig 6 displays the sequential procedures of analysis.

For open coding, the researcher relied on a qualitative analysis tool called QSR NVivo 2.0 (QSR International, 2002), a software application that allows a researcher to import transcripts as text, create codes (termed “nodes” in the program), and highlight and code pieces of text ranging from a few words to a complete transcript. This software was helpful for coding data visually. Figure 7 illustrates an example of the process of open coding using NVivo 2.0 on a small section of transcribed dialogue.

For naming elements and components, I initially put in vivo codes using NVivo2.0 program. After that, I examined a list of codes for each interview transcript, and then I named codes using more abstract terms. During this work, I was able to come up with broader, more comprehensive, and more abstract labels for the codes and groups of codes.

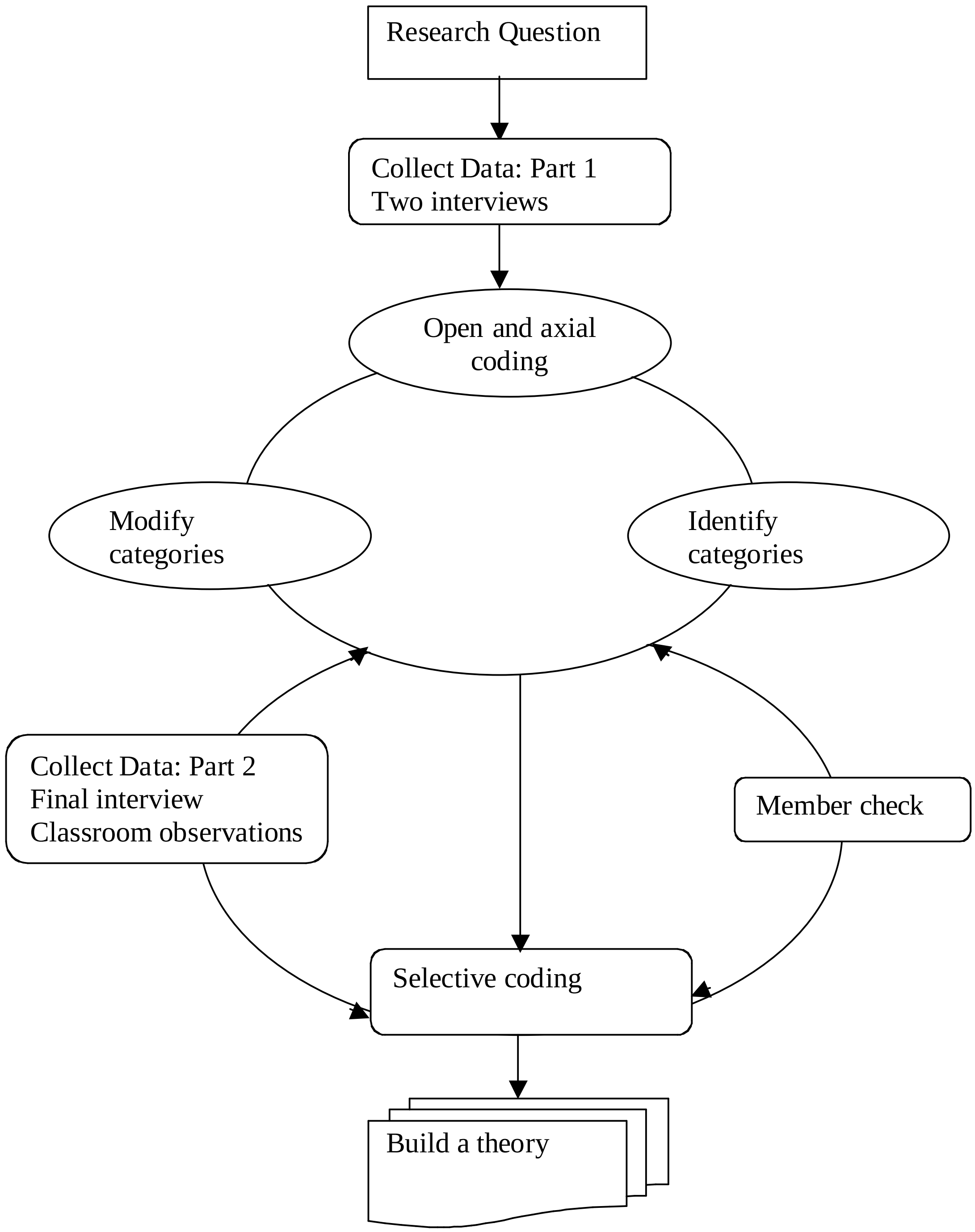
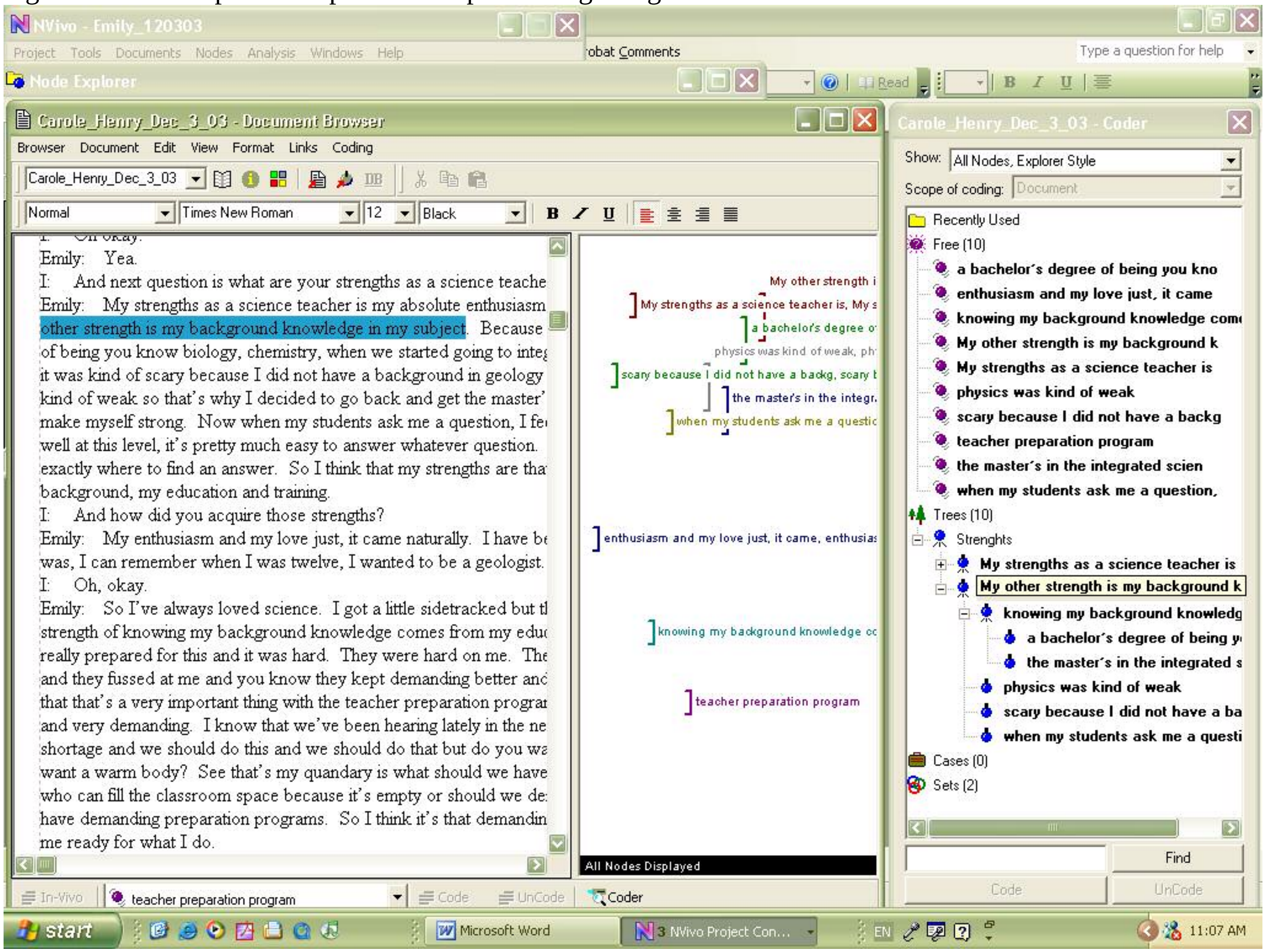


Figure 6. Sequential procedures for data collection and analysis

Figure 7. An example of the process of open coding using NVivo 2.0

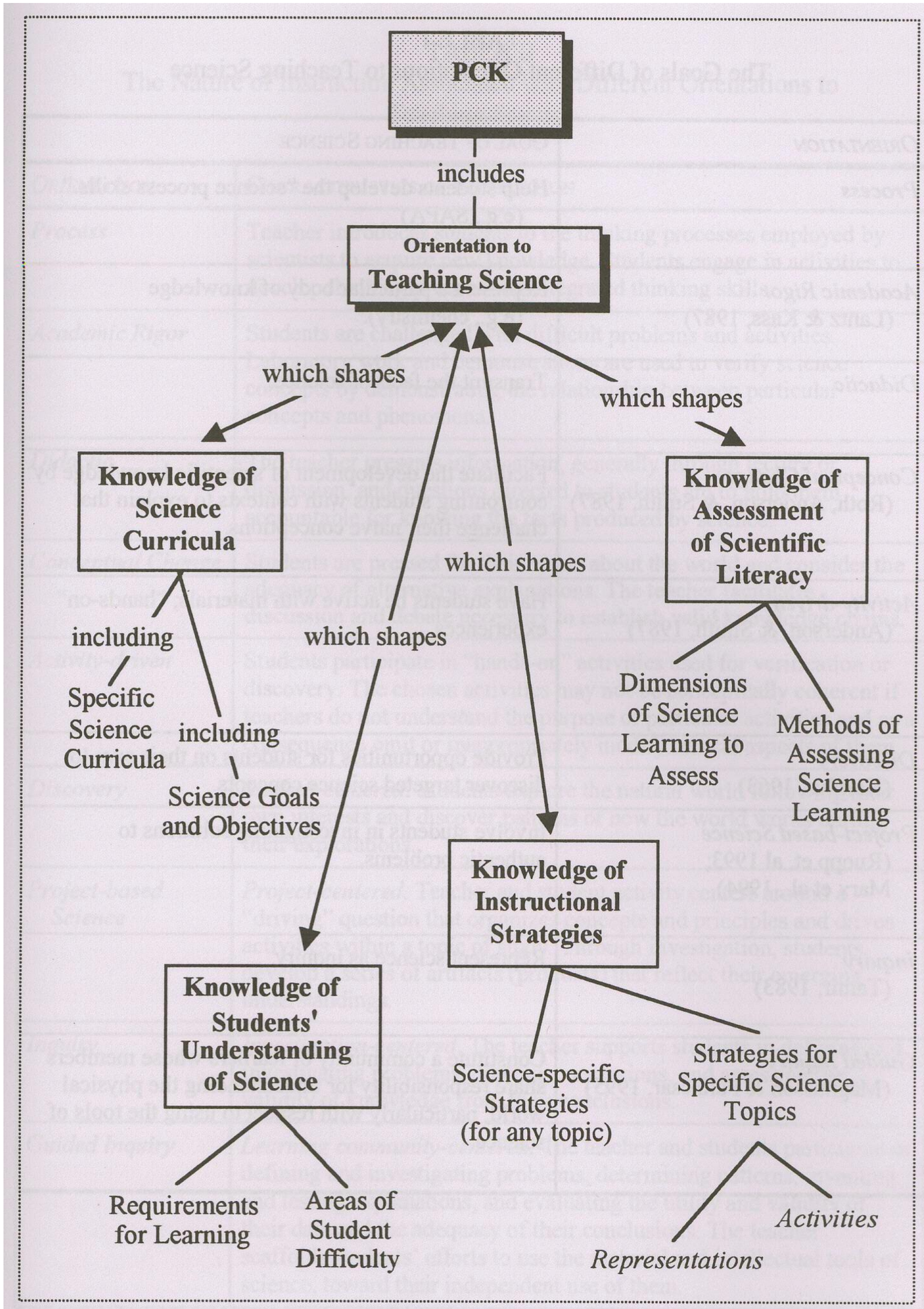


Another source of code names is the literature. Since data analysis was initiated with the conceptualization of PCK for science teaching proposed by Magnusson, Krajcik, & Borko (1999, see Figure 8), their conceptual model of PCK provided a guideline for understanding PCK in the process of exploring teachers' perspectives of PCK in this study. However, as tentative components representing recurring patterns of each teacher's conception emerged, I continued to reshape and modify the categories over the course of the data analysis.

In an attempt to avoid using the same categories as those in Magnusson et. al.'s study (1999), the names for the categories came mostly from the list of concepts discovered in my data. Among the lists of concepts that emerged from the data analysis, ones that stood out as broader and more abstract than the others were used to denote categories.

Through the data analysis process, interestingly, seven common components emerged in all four cases. While the components and elements within each component were initially based on my interpretation of interview data and field notes, I kept reconstructing according to each participant's input over the course of the study. Thus, it is, in part, a co-constructed interpretation between the participating teachers and myself. In the third interview, every teacher agreed upon the components of PCK, with some minor modifications of the elements within the components. The categories and elements that emerged from data analysis for this study will be described at length in Chapter 4.

Figure 8. Components of pedagogical content knowledge for science teaching.
(Magnusson, Krajcik, & Borko, 1999, p.99)



Additionally, the interview transcripts and field notes were used to construct pictures of the teachers' understanding of PCK through the axial coding process. This picture was incorporated into the initial diagram that each participant and I co-constructed during the third interview. We then modified it several times through email communication. During the modification process, I encouraged them to further develop the construct by adding linking words and explaining the relationships among the components.

The diagram was developed by a combination method of "card sort tasks" and "concept mapping" (Baxter and Leaderman, 1999). I showed them the components and elements that emerged from their data and asked them to weigh them according to their importance and to explain them. After that, I asked each participant to make connections among the components to show how they are interrelated within the context of teaching science. After getting a manually-created concept map, I converted it into an electronic version and sent it to each participant. The teachers was asked to check it and to modify it if necessary.

Validity and Credibility

My study incorporated several techniques in order to meet the standards of validity for naturalistic inquiry. First, I achieved triangulation by employing multiple sources for collecting data, including (a) interviews with participants and project personnel, (b) observations of mentoring program activities, and (c) reflective summaries and supplementary materials. Not only would triangulation provide me the means for observing data that might have been overlooked by relying on only one source of data collection, but it would also allow me to see the same data from various perspectives and, in the process, to clarify the meaning of the data in its larger context. Second, I conducted a member check (Lincoln & Guba, 1985) to establish credibility, to clarify meaning, and to check the accuracy of my understanding of the data. Third, I had also discussed my on-going investigation with colleagues. Such discussions served the purpose of “peer debriefing” (Lincoln & Guba, 1985 p. 243). This process was also helpful in developing interview questions and in developing and testing the emerging categories and subcategories.

Summary

In this chapter, I have attempted to describe the methodological approach and procedures I employed to examine mentor teachers’ understanding of pedagogical content knowledge. The rationale for using the case study and the procedure for adopting grounded theory as an analytic framework were discussed at the beginning of this chapter. My experience and background relative to this study were also described because they might influence, to a certain extent, my interpretation of the data. Some discussion about the nature of each collected data source and the way each source supplements the others followed after that. Specific procedures for analyzing data were described and the processes and explanations of utilizing NVivo 2.0 as a technological tool to effectively manage data analysis were illustrated in detail. Lastly, the techniques for enhancing the validity and credibility of the study were discussed at the end of the chapter.

CHAPTER FOUR

RESULTS

> How much and which conceptual details to include and which can be excluded. It all goes back to answering the questions “What was this research all about/” and “What were the main issues and problems with which these informants were grappling?” Then, there should be sufficient conceptual detail and descriptive quotations to give readers a comprehensive understanding of these. (Strauss & Corbin, 1998, p.252)

Overview

This chapter consists of two parts: the description of each case and the overall analyses across four cases. The first part of the chapter is divided into four sections, one section for each case. Each section is titled with the name of the participant and consists of three sub-sections, including each participant’s teaching context; the components of PCK which emerged from the data; and each participant’s conceptualization of his or her own PCK components.

Each section begins with the participant’s personal background as a science teacher and the teaching context related to his or her school and classes. This allows for a better understanding of each participant’s conceptualization of PCK. Next, there is a discussion about the PCK components that the teacher conceptualized. Each component is rank ordered by the teacher according to its importance to teaching science. Interestingly, seven common components emerged in all four cases. While the components and elements within each component were initially based on my interpretation of interview data and field notes, I kept reconstructing according to each participant's input over the course of the study. Thus, it is, in part, a co-constructed interpretation between the participating teachers and myself. In the third interview, every teacher agreed upon the components of PCK, with some minor modifications of the elements within the components.

Concluding the section is representation of each participant's conceptualization of the identified PCK components, a diagram that depicts the teacher's conceptualization of PCK. Each diagram was created from the third interview and revised by exchange of emails for clarification.

The second part of Chapter 4 is a discussion of PCK components across the cases. This part is mainly based on the results drawn from the cross-case analysis. Discussion about each component is briefly presented, then illustrated with examples from the four teachers.

Part One

Wendy's Case

Based on the sampling criteria, Wendy was recommended for this study by the "Teachers as Mentors" program director. She was identified as one of the best mentor science teachers, with a strong science background. When I asked her to participate in this study, she willingly agreed. She told me that she had even participated in an action study research project with a university faculty member seven years ago. She enjoyed this experience immensely. In working with Wendy, I found her to be an energetic and enthusiastic science teacher.

Wendy has an undergraduate degree with a double major in Biology and Kinesiology and two masters' degrees, one in Integrated Science and the other in Biology. She started her career as a biology teacher and coach with a Biology and Kinesiology Certificate and acquired a Composite Certificate through a Master's program. During 28 years of teaching experience, she has taught Biology, Kinesiology, Marine science, Physical science, Marine biology, Chemistry, AP chemistry, AP Biology, Physical science, and GMO (Geology, Meteorology, Oceanography) in four high schools ranging in size from lA to 5A. She is very confident in teaching high school science.

Wendy enjoys mentoring beginning high school teachers in the "Teachers as Mentors" program. She feels her knowledge of science and her experience as a science teacher make her a good mentor. Wendy has served as a mentor in the program for four years and also she presented effective instructional strategies many times at teachers' conferences, both statewide and nationwide.

Wendy believes that her strength is keeping in touch with what is new in science, so she always looks for new ideas and materials, she can use in her science classes. She values collaboration with colleagues in her subject area because she is able to learn from others' experiences, while sharing successful ideas and activities (second interview, 5/18/04). She often discusses and modifies ideas or activities with her colleagues and tries to develop activities that will work better in her science classes. In addition, she is a self-motivated participant in conferences and workshops on professional development. She uses the workshops as opportunities to get new ideas and materials related to science teaching and to share information with other teachers. The following sub-sections describe Wendy's teaching context and explore how she conceptualizes PCK as an experienced science teacher.

Wendy's Teaching Context

Wendy teaches in a high school in a rural area of south Texas. The semester she joined this study marked her fourteenth year at her present school. The majority of her students were White and Hispanic and a small number were African American. She described her students as being neither well-educated nor coming from wealthy families. Most of the students in Wendy's class will find jobs in the local job market instead of going to college (first interview, 12/01/03). She currently teaches Chemistry, AP Chemistry, Biology, AP Biology, Physical science, and GMO. She has six classes a day and each class is composed of fifteen to twenty students. Her students usually include sophomores, juniors, and seniors.

Wendy strives to establish a good rapport with her students. This is evident in the classroom as students frequently ask questions about the topics that are being covered in class. The level of dialogue creates a class environment in which students are attentive to the topic covered and engaged in the lesson (observation, 3/10/05). Wendy's classroom is usually decorated with the products of classroom activities and student projects.

The state requires science teachers to devote forty percent of their science class time to be laboratory work. Wendy typically allocates more than forty percent of class time to hands-on activities and laboratories. She does this because she feels her students would have a better learning experience by being involved in the lessons, as opposed to having just lecture. She also states that most students are tactile learners, so they understand science concepts through doing and seeing science.

During her participation in the study, the laboratories were mostly guided inquiry (she gave students guidelines but allowed students to make some decisions) or verification type activities (she gave them directions and monitored students' progress). She preferred group work with two, three, or four students, as the students helped each other in following the science procedures, and they discussed the questions that emerged during the activity. Wendy valued students' discussion in her classes, while de-emphasizing memorization and regurgitation. She tried to bring real life experiences into her science classes as much as she could and often did this during the laboratory. As students participated in laboratories, they were encouraged to write about their findings and experiences in their science journals. Throughout the semester, Wendy kept reviewing the journals and used them for formative assessment.

As a science teacher, Wendy places great emphasis on conceptual understanding and knowing the vocabulary associated with the concepts because she believes both to be necessary for future learning and real-world application. Additionally, for those who have difficulties with understanding what they are doing, Wendy personally tutors them after school.

The following subsections discuss the knowledge components for science teaching from Wendy's perspective, as well as her conceptualization of those components to form a construct of PCK.

Wendy's Components of Knowledge for Teaching Science

In the process of analyzing Wendy's interviews and my observations of her class, seven distinct components emerged to form her PCK for science teaching. These components include knowledge of (1) science; (2) students; (3) goals; (4) teaching strategies; (5) curriculum organization; (6) resources; and (7) assessment. Within each component, the specific elements indicate that each knowledge area is not only includes static knowledge, but also dynamic skills. I will describe the seven components and specific elements within each component in the following paragraphs. Each component is discussed in the order, Wendy assigned, according to its importance in teaching science.

Wendy's component 1: knowledge of science.

When I asked Wendy to weigh each component according to importance to science teaching, she rated the knowledge of science highest. Particularly, she put a great emphasis on knowing scientific content saying:

> Obviously, if you don't have the content knowledge, it will be hard to be a science teacher. I guess some teachers do it by trying to stay like a chapter ahead, but I think it will get you in trouble because students don't stay within the chapter. What about they go some by themselves and bring some questions from outside. They wouldn't

> necessarily be on that [chapter]. So, I would think that would be a number one for the science teacher (third interview, 3/10/05).

This knowledge area also includes the nature of science and the scientific inquiry process. Wendy tries to get as many students as possible engaged in lab activities because she believes most students are tactile learners. Furthermore, Wendy considers laboratories as opportunities to learn science. She tries to use laboratories that demonstrate a principle through the process of science. Furthermore, she values the process of doing science over the results of investigations (first interview, 12/01/03). The following quote describes Wendy's view of laboratory activities:

> I think a lot of times they expect stuff to happen even if it's not supposed to happen. And you try to tell them, in science, a lot of our discoveries were made through accidents. They weren't even doing these experiments for this and it went off someplace else — but that was a good thing, because then we discovered a new pharmaceutical product. You try to tell the students that mistakes in science are not always bad. And I think it is going along with the discipline of science completely (first interview 12/01/03)

Another element included in the knowledge of science from Wendy's perspective is the knowledge of current issues in science. Wendy actively participates in professional development workshops to learn current scientific issues and how to incorporate them into her lessons. She believes that her effort to keep up with recent developments in science is essential because the body of scientific knowledge is always updated by new findings through scientific research (third interview 3/10/05).

Wendy's component 2-a: knowledge of goals.

Wendy reported that goal setting in science teaching is given the first priority in her teaching practice because it guides "where to go" (third interview, 3/11/05). Two main elements are included within this component of PCK: scientific literacy and a real-world application. While these two elements seem to be similar, Wendy draws some distinctions

I adopted the definition of "scientific literacy" used in the National Science Education Standards [NSES] (NRC, 1996). According to the Standards, "scientific literacy" includes "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity related areas" as well as "specific types of abilities" shown in the content standards of NSES (p. 22). Wendy offered an illustration of the importance of personal scientific literacy. Specifically, she said:

> I know obviously that all students I have are not going to college. They are not all going to be doctors, but I think learning science helps you be a better problem solver and a better thinker and if you are that [a problem solver and thinker], then it helps you in any part of your life (second interview 5/18/04).

Her goals are to have the students learn about science, the skills found in science, and how to participate in society. Her lessons are configured designed to achieve these goals.

She also emphasized the importance of getting her students to apply what they learn in her class to their real lives, saying:

> I try to bring in real-world applications to my science class, not just what is in the textbook. Because so many kids say, "well, I don't need algebra because when am I going to use it again?" I don't want them to say that about science. I want to show them that chemistry has a lot to do with everything, too. I try to bring the real-world applications in too (first interview, 12/1/03).

She also tries to link daily life materials and phenomena to her lessons by using them as attention-getters, or assigning students month-long projects. During one class observation, she assigned her students a project called "Just hangin' around real world reactions" (see Appendix). This project, according to Wendy, relates to the everyday uses of chemical reactions. Wendy described the project as follows:

> Students choose a reaction. Then, I will give them a very simple example like $2Na + Cl_2 \rightarrow NaCl_2$. They put this on a hanger and then attach it to the sodium place; they have to hang two labels that shows the elements, sodium, two labels that show the chlorine elements, and then one label that shows sodium chloride. The labels are the ingredients labels found on products at the store. This

> activity gives them real-world applications of reactions and compounds and elements that are used in their everyday lives (second interview, 5/18/04).

Wendy believed that this was a good activity because it reviewed all five reactions, showed the students real life examples, and directed them to start reading labels. She also believes that her students can make better choices in real life as they now know what chemicals are harmful and which are not, which also benefits them.

Wendy's component 2-b: knowledge of students.

Wendy gave equal value to "knowledge of goals" and "knowledge of students". She reported that these two components are the determinants of both what to teach and how to teach. From Wendy's viewpoint, the knowledge of students embraces (1) students' prior knowledge, (2) variations in students' learning, (3) learning difficulties, (4) students' real life experiences, and (5) the home situation. While the first three elements are already discussed in the previous studies in the literature (Magnusson et al., 1999), the remaining two elements seem to be new elements within "the knowledge of students" components. Therefore, I will focus on these two new elements. Wendy provided an example of how she used students' real-life experiences to help them better understand scientific concepts:

> I used to put a lot of real-life situations that students are likely to experience in their daily life. For instance, you are driving in a car and you are making a curve and your glasses go flying off the dash, "What law does that relate to, and why?" (first interview, 12/01/03).

She also linkedth is element to her use of assessments. Instead of multiple choice questions to evaluate her students' understanding, she develops short answer questions about science concept related to real-life situations.

For Wendy, knowing the home situation of the student is another element of "knowledge of students". When she assigned a project, she usually encouraged students to work on it with their family members, discussing the topics related to the project. Wendy felt that involving the family helped students to enjoy and be fully engaged in the project.

Wendy's component 3-a: knowledge of teaching strategies.

This component of PCK refers to the knowledge and skills of "how you are getting there" according to Wendy's definition (third interview, 3/10/05). The elements within "the knowledge of teaching strategies" are: (1) effective attention getters; (2) a variety of lab activities (for instance, demonstrations, simulations, etc.); (3) useful analogies; (4) students' discussions; and (5) a variety of projects.

Wendy tries to make connections between what students learn in her class and their daily lives by using attention getters that represent the real world. For example, in the lesson about the difference between a mixture and a compound, she used the cereal Total® as an attention getter:

> I start out and ask them "What did you eat this morning?" And someone will say "cereal." And I will ask, "What was in it?", "Milk." "What else was in it chemically?" "I don't know." I said, "Don't you mind what you don't know you know?" And I talk to

> them about, the cereal Total®. And I usually have a box here at that time and I will pour it out and I put the milk in it and then I will get a magnet and I run it across and all the little iron fillings come up. Students say “Wow.”. And I said to make it Total®, the only way they could put iron in it was to put iron filings in it. (second interview, 5/18/04)

Wendy believes that an effective attention-getter engages students in the lesson and makes the lesson successful. She usually spends a lot of time coming up with an idea for an effective attention getter while planning her lessons (third interview 3/10/05).

When it comes to her teaching strategies, Wendy reported that she makes an effort to design laboratory activities to be student-centered:

> I used to lecture a lot and I don’t do as much of that any more. A lot of my labs used to be cookbook layouts and now they are more inquiry based or even I have the students design a lab. (first interview, 12/01/03)

She reported that she was able to determine “what works” and “what has worked” throughout her years as a high school science teacher. She also stated that, though “things worked in the past, they don’t necessarily work in the future. It depends on the kids because the kids do change” (first interview, 12/01/03). Another teaching strategy that she uses for students’ better understanding of science is to let them discuss the conclusion after a lab activity. She believes that discussing their findings with supporting evidence with other students is one of the characteristics of scientists, as well as a better way to understand the concept in a solid manner (third interview, 3/10/05).

Wendy assigns her two projects every semester to her students to provide personal learning opportunities. She reported that this strategy was more successful than she had expected:

> I decide how I am going to do this, and obviously [as this is] science I am going to let the students do some labs and research on their project. Even a lot of parents said that they learned a lot because they were looking for stuff, too. A student would say "I need something with barium nitrate," so they are even learning. It is kind of extended out even more than I thought (second interview, 5/18/04)

Wendy stated that she has acquired new ideas for student projects while participating in science teaching focused workshops.

Wendy's component 3-b: knowledge of curriculum organization.

Wendy believes that the knowledge of curriculum organization is closely aligned with the knowledge of teaching strategies and knowledge of resources. Interpreting her perspective on this component, I found that she views this component as a required skill for being a good science teacher. The elements within this component includes: (1) state standards of science (Texas Essentials of Knowledge and Skills [TEKS]); (2) state standardized test (Texas Assessment of Knowledge and Skills [TAKS]); (3) skills to select what to teach; (4) skills to make connections between the units; (4) skills to organize the lesson in a specific order; and (5) flexibility.

Wendy's definition of "curriculum" was "what a teacher needs to bring out" to the class. She stated that the knowledge of curriculum is not only the curriculum itself, but also the skills to organize the curriculum (third interview, 3.10/05). To make a decision of "what to teach," she referred to the state standard of science, that is, TEKS (first interview 12/01/03). She also reported that TAKS is another reference to guide the curriculum because this state standardized test is very important especially in high schools (third interview 3/10/05). In explaining the reason for referring to the standards, she said, "We have to look at the TEKS and TAKS because we have to cover them all, so that's a major portion of my planning" (first interview, 12/01/04). In addition to these standards, in Wendy's perspective, a science teacher needs the ability to select "what to teach". This decision should be made by a teacher because, she believes, the standard does not provide a holistic blueprint of school curriculum.

Making connections is another important skill required for all science teachers. Wendy believes that the students learn better when a teacher makes connections among science concepts and other subjects (second interview, 5/18/04). To do so, a teacher also needs to be skilled at organizing the units or lessons in a specific order. Wendy said:

> Generally the curriculum itself is pretty well set. If you have to teach the TEKS, I would think I'd try to go, especially like in

> chemistry when things build upon each other. I need to go in the correct order. I can't start off with them writing compounds if we haven't even talked about symbols or ions or charges. Obviously we can't do that, so it has to be in a specific order whether they [the students] can keep building upon it (first interview, 12/01/03).

Another element that is included in the knowledge of curriculum is "flexibility". Wendy emphasized that a science teacher should be flexible, because a science teacher can have unpredictable situations or limited materials during the laboratories or activities (second interview, 5/18/04).

Wendy's component 3-c: knowledge of resources.

Wendy reported that this component of PCK is the complementary knowledge area of two components previously discussed — "knowledge of teaching strategies" and "knowledge of curriculum organization" (third interview, 3/10/05). Although she reported that science content knowledge is an essential component of teaching science, she also stated that the science knowledge of science teachers tends to be general rather than specific (first interview, 12/01/03). For this reason, she stated it is necessary for a science teacher to be aware of available resources to find the answers. In her viewpoint, the knowledge of resources refers to (1) the knowledge of materials including worksheets, hand-on activities and lab activities; and (2) knowledge of media and technology.

Wendy's component 4: knowledge of assessment strategies.

Wendy ranked this component of PCK is lowest, because it is usually considered to be subordinate to "teaching practice". She usually applies this knowledge area to readjust her lessons and teaching strategies. She stated how she determined whether or not students understood by the questions from students:

> I think I judge whether my lesson successful or not by questions the class will ask. We do a pre-lab and a post-lab and so I read their labs —which are written out — and I read them so I can get an idea if they got it or not. And then obviously, when we do post-lab, the questions that are asked, I can tell if it went the right direction or not (first interview, 12/01/03).

She also uses short answer tests after every unit. All questions in a short answer test are developed based on real world situations, so her students can utilize what they have learned in her class. The students should explain why it happens or how it works in order to answer the questions properly. She believes that this is a good assessment method for understanding how students make connections between the lessons and the real-world situations.

Another strategy for assessment is that she urges her students to develop a rubric for a project or a lab activity. She believes that the students can clearly capture the objectives and the concepts related to the project or lab activity in the process of rubric development (third interview, 3/10/05). She thinks that the students also benefit from training in self-assessment, which helps them determine what they need to do. She reported that she uses her students' rubrics in thirty percent of her assessments and usually the rubrics developed by her students are harder than the rubrics she develops.

Reflecting upon her assessment strategies, the purpose of her assessment seems to be one of "formative assessment" (NRC, 2001), in that the teacher uses assessment to assist students' learning.

Wendy's Conceptualization of Seven PCK Components

Wendy agreed that the seven components are essential knowledge areas for science teaching, and that these components are interrelated and interact in the lesson plannig, as well as in teaching practice (third interview, 3/10/05). Figure 9 shows how she conceptualizes PCK with the seven components. Wendy and I co-constructed the diagram during the third interview. We then modified it several times through exchanges of emails. During the modification process, I encouraged her to further develop the construct by adding linking words and explaining the relationships among the components. The diagram was initially created by a combination method of "card sort tasks" and "concept mapping" (Baxter and Leaderman, 1999). I showed her the components and elements that emerged from her data and asked her to weigh them according to their importance and explain. After that, I asked Wendy to make connections among the components to show how they are interrelated within the notion of teaching science. After getting a manually-created concept map, I converted it into an electronic version and sent it to Wendy. Wendy was asked to check it and to modify it if necessary.

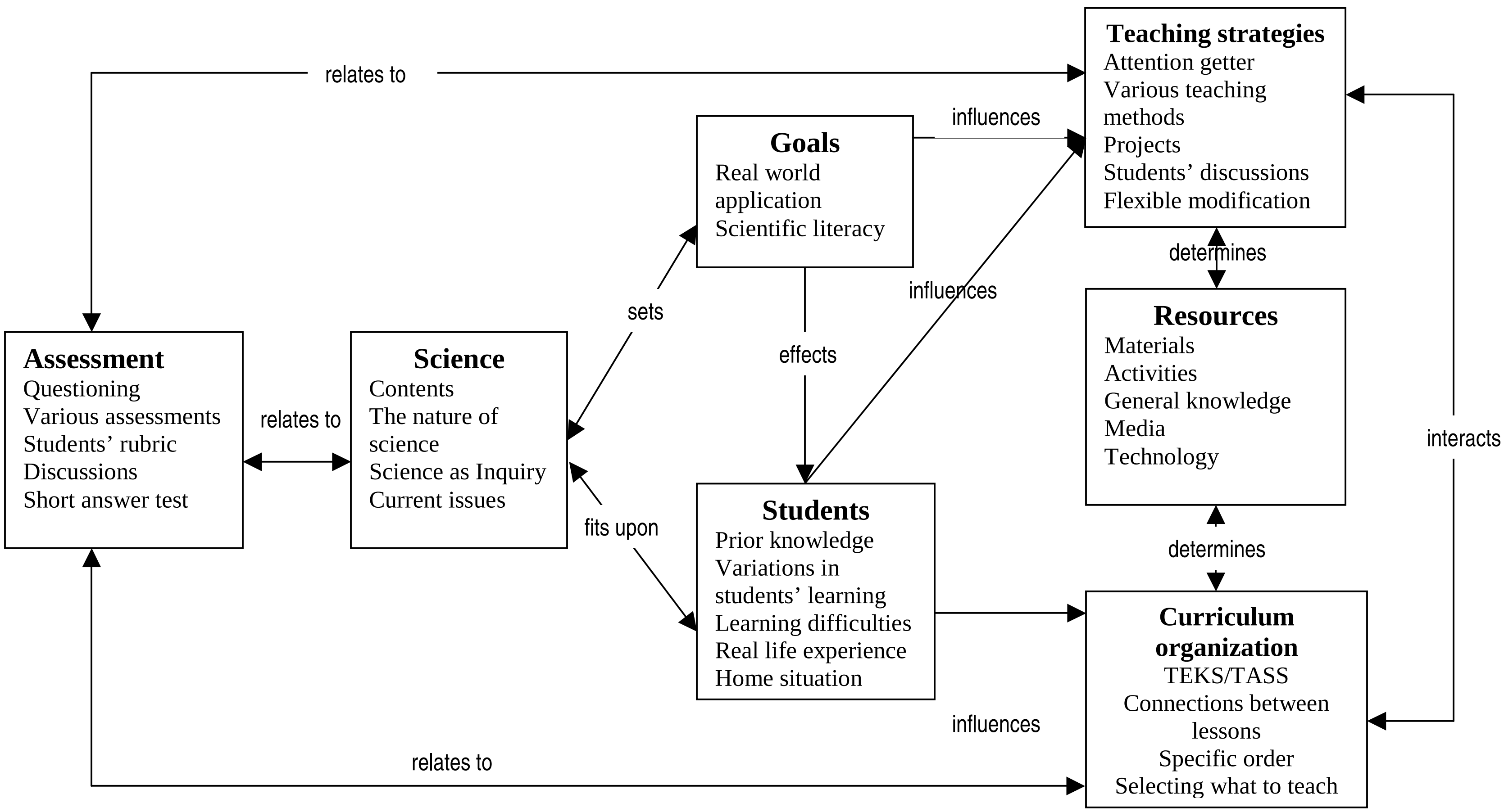
She stated that "knowledge of science" sets the goals and should fit the students. Her ultimate goal is to affect the students. The teaching strategies and curriculum organization are determined by the goals and bythe students. She believes that knowledge of curriculum organization (what to teach) and the knowledge of teaching strategies interact with each other. When they interact, knowledge of resources determines what to teach and how to teach.

Wendy believes that the seven components are interwoven and influence each other in teaching science. For example, the knowledge of science is strongly related to the knowledge of the goals. The knowledge of the goals determines the teaching strategies:

> I think, especially in science, there are so many things that haven't been found out yet and if we don't have kids that are into that, we are never going to find them out. We have to have people that have inquiring minds. You will have the students do a lab and they will go and have questions. "What if ?" or "Can I now do this?" That's what we need. We need more minds like that. Otherwise we are going to stop inventing new things and finding new vaccines and stuff. So, I think it's a big deal. And if we don't try to get them into the inquiring mood here, where is it going to come from if we don't do it in school? (first interview, 12/03/03).

When she was asked to name the group of knowledge components, Wendy titled it, "Essential knowledge areas for science teaching." She believes that these essential knowledge areas are developed over years of teaching experience. She also thinks that participating in workshops helps science teachers enhance their knowledge and learn new strategies for science teaching. (third interview, 3/10/05).

Figure 9. Wendy's conceptualization of PCK
(Essential knowledge areas for science teaching)



Shawna's Case

Shawna was recommended for the study by the "Teachers as Mentors" project, with which she had worked on several projects. Shawna was actively involved as a leader in the mentoring program and had an excellent reputation in her school district. Although she was very busy with her school work, her mentoring project, and her graduate school work, she was interested in the study and agreed to participate. Of the five participants, Shawna was the only one whose entire career had been exclusively in teaching. She had thirty-three years of teaching experience. She invited me to observe three of her science classes which included students of varying abilities. She showed me the files that she had accumulated for each class, which included activity list and the like. She often explained at length as she answered my interview questions.

Shawna has an undergraduate degree in Elementary Education and a Masters' degree in Educational Administration. She is currently pursuing another Masters' degree in Integrated Science Education. Although she has the credentials to become an administrator or principal in the district, she has decided to stay in the classroom. When I asked her the reason, she said, "because I love teaching" (first interview 11/24/03).

When Shawna started teaching, sixth-grade was taught at the elementary school level, but it later was moved to middle school. Her career began in an elementary school, and she has taught sixth-grade science at middle school for over twenty years (out of thirty-three years total). She has taught at her current middle school for ten years.

Shawna said that she learned how to be a good science teacher through trial and error (first interview 11/24/03). She had also been influenced by a mentor, who really helped her understand the social aspects of the children. She believed that good science teachers should never stop thinking and looking for opportunities for professional development. While working with her, I found her to be a thoughtful and reflective teacher. She is also very active in her professional development and takes pride in being a lifelong learner.

Shawna's Teaching Context

Shawna teaches in a school district in a town outside of San Antonio. Her middle school has a student population of approximately 1,600 students. The majority of her students are Hispanic and Caucasian, along with a small number of African-American students. She stated that most of the students in her class come from families with low socioeconomic status, and she considers that fact when planning her lessons (first interview 11/24/05). She teaches six classes a day, and all of them are sixth grade science classes, composed of fifteen to twenty students. Shawna divided her six classes into three groups according to the students' levels of understanding and ability. She used different activities with similar objectives to help the studentsunderstand science better.

She was associated with many science projects both locally and nationally, such as Global Learning and Observation to Benefit the Environment (GLOBE), an inquiry-based environmental science curriculum, and the Jason project, a hands-on inquiry program. She often invites scientists to her class to demonstrate to her students what scientists do and how they do it. She wants to encourage her students to think of themselves as scientists by acting and thinking as scientists. She also knows of many local informal science education centers and uses them as resources to teach about the local issues that are closely related to the students' daily lives. For example, when teaching the "water" curriculum, she uses SAWS — the San Antonio Water System — as an organization where she can access useful materials and information for her and her students. In doing so, she encourages students to think about local issues and take responsibility as problem solvers.

Shawna emphasizes hands-on experience in science learning, so she tries to incorporate as many activities as possible into her class. She believes that students at that age learn better by doing. She also believes that activities should be connected to make students' learning meaningful. She urges students to keep science journals, in which students record data, tables, figures, and questions that come out during activities and experiments. Students are required to complete the journal byincluding findings and conclusions after each experiment or activity. Shawn uses the journals as one of her assessment materials.

In the following sections, I will describe the components and elements of PCK from Shawna's perspective and summarize how she conceptualizes these components as a knowledge base for teaching science.

Shawna's Components of Knowledge for Teaching Science

Shawna's data pointed to the same seven components that had emerged from Wendy's; however, she ranked them differently than Wendy had. Each component will be described according to the importance attributed by Shawna.

Shawna's component 1: knowledge of science.

This component of PCK did not initially emerge from Shawna's data until the third interview was conducted. While she and I were looking together at the codes and components in the third interview, Shawna decided that she wanted to add this component to the body of PCK components. She reported that this component is the fundamental knowledge for science teaching. This component includes science content knowledge, integrated science knowledge, and understanding the spiraling effect.

She believes that a teacher has to continually enhance her content knowledge and undo any misconceptions (third interview, 3/11/05). To do so, a teacher needs to go back to college again because certain areas of science content as in Physics or Chemistry, can only by learned in depth in class. She also believes that middle school teaching is more difficult than high school teaching because a teacher should know all areas of science content. She stated:

> The most difficult area is middle school because we have to teach all of the sciences. In high school, they only have to be strong in one science. They only teach one science like a Chemistry teacher is teaching Chemistry, a Physics teacher is teaching Physics. They

> should integrate, but [they] don't always do that. But, in a middle school, we have to teach all of them, so how strong of teacher do we need to be? Much stronger; you need to be more knowledgeable (third interview, 3/11/05).

Shawna stresses that middle school teachers should have the ability to integrate the science content across all the areas of science. She tries to incorporate the aspects of Physics and Chemistry that are related to the Biology lessons (She teaches sixth-grade science at that time). She also believes that an understanding of "the spiraling effect" is another part of "knowledge of science content" for middle school teachers. She explained:

> The spiraling effect — that is what we need. We got some grade level-to- grade level; like for six graders if we introduce something for the first time, [then, when they become] seventh graders, [they] will pick up on it and review it and add to it. So, we need to know what the depth is going to be or should be, and I think teachers have a very difficult time with that. What happens is at "all-level," a teacher teaches the same thing and that shouldn't be so. The students are supposed to get more depth of that topic in the next grade level (third interview, 3/11/05).

Her understanding of "knowledge of science" seems to mean the "knowledge of curriculum organization." However, she believes that all these elements are included in the area of knowledge of science, particularly in the middle school teaching context.

Shawna's component 2: knowledge of assessment strategies

Unlike other teachers cases, a great emphasis is placed on this area of knowledge because Shawna usually uses a "backward design" to develop her lessons and units. She believes that assessment should be ongoing. She explained:

> "Backward design" starts with my assessment and I build the units. So, I am really choosing the activities that address what I want my students to know. So it is really good because what it does is that it forces teachers to choose quality activities in the first place. They have quality activities and have a reason for what you are doing. So many of the teachers do the activities because it is fun or they do like doing enough activities, but that doesn't mean it is necessary to teach concepts that they supposed to teach (third interview, 3/11/05).

She divided assessment strategies into two categories: formal versus informal. According to her categorization, formal assessment includes exams, authentic assessment, and problem-based assessment; informal assessment includes questioning, classroom discussion, lab debrief, and daily assignments. She considers informal assessment as on-going evaluation to diagnose what her students understand and learn. For instance, she said, "Assessing to make sure — what exactly my students are taught now — then I could build on a higher level of learning" (first interview, 12/24/05). She uses a variety of informal assessment strategies in her class.

She stated that the purpose of formal assessment is two fold: (1) to evaluate students' understanding about science concepts in the units; and (2) to help students integrate what they have learned and apply it to real life. Regular examination is usually used for the first purpose. Project-based assessment or authentic assessment is used for the second purpose (third interview, 3/11/05). She distinguished authentic assessment from project-based assessment. She defined "problem-based assessment" as being when students identify the problem in a simulated situation and then come back with the solution for how to address the problem. Meanwhile, "authentic assessment" depends on students' real-life situation or real-life problem. She explained:

> Once the lake across the road [near the school], all of sudden, huge amount of fish killed and they had to identify what the problem is, what caused that fish kill. And then, make a recommendation that prevent from the problem from happening again. They did a "simulation" where they do — gather their data and analyze their data. And make a presentation to the city board of directors or something like that (third interview, 3/11/05).

She tries to include more authentic assessment as her formal assessment. Shawna values making connections between her science lessons and students' real lives, and she believes that this type of assessment helps her to achieve the goals of her class, for example, scientific literacy.

Shawna's component 3: knowledge of goals.

Shawna's definition of this component is "what I am aiming for in my science teaching" (third interview, 3/11/05). This component includes (1) scientific literacy; (2) understanding of science concepts; (3) scientific communication; and (4) making connections to real life.

Shawna wants her students to be life-long learners and to solve problems by applying their understanding of science to real life. She stated:

> My ultimate goal is for them to love what they learn and to keep searching for answers. I want them to be life-long learners. Science is what drives our world. Everything keeps going right back to it. So, I believe their lives would be better if they would be stronger in science. If kids say, "well, what do we need science for?" I will say, "Everything is science. Everything is." Every time we read about something or see something on the news or something happens at home or they see something on their way home or out in the courtyard, everything relates back to science (second interview, 5/21/04).

An understanding of science concepts is necessary for students to further utilize the concepts in the future. She said, "Even though they don't become scientists, they still use science everyday. I want them to be more knowledgeable in science. And it's really important" (third interview, 3/11/05). She encourages her students to communicate scientifically in the class. She commented, "The students should be able to explain it and to share their knowledge with other students or family members" (second interview, 5/21/04). Although she believes that a scientist should do that, she admitted that it is difficult to get students to convey what they are thinking in this manner. She said, “It is a real challenge keeping them talking like the scientist rather than jive talk from the neighborhood. I have to constantly keep reminding them of when they give an answer or explain what they think” (second interview, 5/21/04).

She believes that it is important to make connections between what her students have learned in class and their real-life situations. When I asked for the importance of an activity that she had developed, she explained:

> Because it shows how they are good stewards of the earth and they can make a difference as an individual. Here in San Antonio, water is a big issue and that’s what this [activity] is. The name of it is “Incredible Journey.” The kids are responsible for being good stewards and conserving water and a lot of times they don’t know what they can do even as young as they are, whereas with the unit, they can (second interview, 5/21/04).

Shawna believes that students better understand the knowledge when they can use it. She said, “I assume that they actually do understand things because they can relate it to their real lives more than just a bunch of words on paper. I feel the assumption is true” (second interview, 5/21/04). In spite of time constraints, she tries to implement her beliefs as much as possible in her classes. She said:

> I think that our learners have a hard time grasping concepts and making those relationships and I would much rather take more

> time to cover them than hurry up and get through the material just because it has to be done in a certain part of time. So, I think we need to take the time that is necessary for them to make that connection. (second interview, 5/21/04).

Shawna's component 4: knowledge of curriculum organization.

Shawna refers to the knowledge of curriculum organization as "how it should be organized" (third interview, 3/11/05). She thinks that knowledge of curriculum organization is a crucial part of science teaching. Her strengths as a science teacher come from this area of knowledge. She stated:

> I understand the big picture of curriculum. It is very difficult for the teachers to know what should be taught and when to teach it. And I am a person that does not like to go by the book. When you build units, you can teach across all the subject areas. And that's what makes teaching fun, because you are building all of those activities rather than using the books only. And the textbook you can use as a resource. It should not be the primary factor (first interview, 11/24/05).

This component includes seven elements that indicate specific knowledge of curriculum per se, as well as skills to organize her science curriculum, including (1) state standards (TEKS) ; (2) curriculum vertical alignment; (3) integrating science subjects; (4) developing interdisciplinary lessons; (5) expanding on a concept; (6) linking local issues to the lesson; and (7) making connections between activities.

While she considers a sixth-grade science textbook as a resource and reference, she uses TEKS as a skeletal framework for her curriculum organization. She said, “I consider TEKS, but I think it is just a bare minimum. It is just a small amount of what they need to know for science so I try to bring in even more than that”(second interview, 5/21/04). Shawna also considers curriculum vertical alignment across the grades. She said, “I look at what is being taught over the grades and see the concepts from the other grades. I think it is good because it is connected between grades” (first interview, 11/24/05). In addition to the vertical alignment of curriculum, she also reports that she needs to know how to integrate all science subjects for building lessons because — at the middle school in Texas — science teachers have to teach all areas of science. She thinks that this situation is unique to middle school science teachers. She stated:

> When you teach chemistry, you don’t teach chemistry. I mean there are other concepts that would go into other sciences; like earth science, there is a lot of chemistry in earth science. It is hard because you have to be well versed in all of them, and a lot of teachers are not. But, if you are going to teach in middle school, I think you have to know more than just one isolated [science] field. (first interview, 11/24/05).

Shawna also placed emphasis on skills for developing interdisciplinary lessons. She tries to incorporate other subjects into her lessons and develops interdisciplinary lessons. She believes that science is the subject that she can integrate essential features of other subjects with, such as math skills and writing skills.

Shawna's component 5: knowledge of students

Shawna considers "knowledge of students" to be very important. She believes that this area of knowledge is crucial in choosing teaching strategies. She thinks that a knowledge of students cannot be acquired without student teaching experience and classroom experience. This component includes six elements: (1) students' needs and types; (2) students' difficulties in learning; (3) students' different abilities; (4) students' real life experience; (5) previously learned knowledge; and (6) students' misconceptions.

She considers her students' needs and types, different abilities, and difficulties as she plans her lessons (first interview, 11/24/03). For example, she said:

> Our kids are very mobile. Their attention span is very short. Fifth graders and sixth graders' attention spans are only about five, ten minutes and they should be thirty minutes long, but this kids -- this is a very high poverty area -- so these students are very used to a lot of noise, a lot of movement at home so they bring that to school and they have to have a lot of noise and a lot of movement here, so the more they are moving, but still actively engaged, the better. They are not very good about sitting and listening, so that strategy is very important for our kids, the type of students that we have here.

Shawna stated that students' difficulties are related to their reading and math skills because those are basic skills that are required for learning science.

Another element that affects her lessons is "students' knowledge that has been previously learned." She thinks that understanding students' previous knowledge is important because it is the base on which to build students' further understanding of science concepts. She often changes her lessons or teaching strategies when she finds that students lack previous knowledge. She reviews and re-teaches the basic concepts first and adjusts her lessons to the students' levels of understanding (first interview, 11/24/03). She also considers students' real life experiences. She believes that by applying real life experiences to activities or lessons, she helps her students to get motivated and engaged in their learning.

The last element in this component is "students' misconceptions." Shawna reported that sixth graders came to middle school with a lot of misconceptions, and she tries to undo that thinking and change it. She said, "If they [the students] have misconceptions, then they do not understand" (third interview, 3/11/05). She explains:

> For example, we were talking the other day about the seasons of the year. They think the earth [gets] closer or further away from the sun, [and] that is why we have the seasons, and it's not. It's the angle at which we are, we're either pointed toward it or pointed away, based on the hemisphere [of] that land, whether we are northern or southern. That's a very common misconception. So,

> they don't understand the season if they don't understand the further or closer (third interview, 3/11/05).

Shawna reported that the misunderstandings of elementary school teachers lead to the students' misconceptions, because the teachers pass them on to the students.

Shawna's component 6: knowledge of teaching strategies

This component refers to "how science should be taught" and "how do we get there," consisting of the following seven elements: (1) brainstorming, (2) choosing quality activities, (3) building and refining activities, (4) simulations, (5) guided inquiry, (6) hands-on laboratories, (7) field trip, (8) safety, and (9) flexibility.

She believes that the brainstorming process is an integral part of students' engagement in learning science. She described one of the eye-catching activities that was successful:

> A simulation of a grain elevator explosion is always an eye catcher, when I teach properties of matter. [There are] the physical properties and chemical properties. The kids never understand those and to make sure that you have physical properties that can cause the physical changes and the chemical properties are part of the physical changes. So, I put cornstarch in a pile and they are unable to ignite it with a propane tank [torch], but when they hold [the] propane tank [torch] up in the air and I shut the lights out and then I blow, I use probably two handfuls of cornstarch in that flame. That was the kids were just in awe. It's unbelievable things, and they

> would not think it's science. Then I teach the science concepts (first interview, 11/24/03).

Related to this element, she also included the knowledge of safety in this component, because knowing information related to safety is important as a teacher plans activities and laboratories. If the activity or laboratory is considered dangerous, she often changes her teaching strategies.

Another element is the ability to choose quality activities. According to her explanation, good quality activities are needed to meet diversified students' types and needs. She said, "Quality activities to teach the science are not just for the fun but [also] understanding the concepts" (first interview, 11/24/05). In addition, building and refining activities is another required skill for a science teacher. Shawna stated:

> The experience tells me, "I am a creative teacher." So, I can build an activity and look at it. [I will] say, "This is going to be able to teach that concept." And it normally does. Sometimes the activity does not go well, but I'll go back and refine it. Like our textbook has different labs, but I don't think they are as good as the ones I've developed over the years. So, you begin to see that some activities work better than others and that only comes from trying them. If they don't work then a teacher needs to refine them. If you have tried them a couple of times, they still don't work, then it's time to think of something else (second interview, 5/21/04).

She thinks that middle school students tend to understand better if they can see it. Therefore, she tries to simulate as many science concepts as possible. She often collaborates with her colleagues to further develop her ideas for simulations. She also makes an effort to have a field trip to provide her students with real experiences. For example, she explained one of her favorite lessons:

> I like the water curriculum mainly because this is one where I can do the trip down to Port Aransas. A lot of times we teach things in class and the kids don't get to really see it. Until the kids really experience it, it doesn't make sense to them. When we go to Port Aransas, they actually see the dunes. They can actually see erosions. They can actually see the organisms, even the water cycle. All of it is all there, so they begin to see a relationship to what they were learning in the classroom. This is why [it's] my favorite one. (second interview, 5/21/04).

Along with the emphasis on real experiences, she also prefers hands-on activities. She believes that the students learn when they are fully engaged in the activities. She also incorporated inquiry laboratories into her lessons, but she believes that students at the middle school age learn better when clear guidelines are provided. She opposed the idea of open inquiry:

> I feel most of my class learn by doing, so they came up with the answers and questions. I know there are a lot of teachers, they brought inquiry, but the way I design inquiry laboratories is

> different. I give them a certain amount of information and then they engage in laboratory activities and they are able to see the knowledge at work or be able to tell and guess. I don't think the kids can learn if they do inquiry only. While the students are doing inquiry, how do they ever know they are on the right track or not? Because, I found that there are a lot of kids with a lot of scientific misconceptions and they don't ever get those clarified so they go into college and universities level [courses] and they have the wrong information. As a science teacher, I have to be a person that relays information to them and then they [the students] are better able to do science and see it. So a lot of my inquiry laboratories are [the ones in which] they can see it, they build it and experience it and then they are able to propose more questions to test. And, I think when kids begin to ask questions, then they are beginning to make connections (first interview, 11/24/03).

Shawna also stressed that a teacher should be flexible in the use of teaching strategies. She often plans different activities and tries to vary them according to the students' responses and understanding. By having various teaching strategies to choose from, she thinks that a teacher can meet the different needs of her students (second interview, 5/21/04).

Shawna's component 7: knowledge of resources.

"Knowledge of resource" refers to the knowledge of "where to go get information," according to Shawna's explanation. This component is jumped together in a group with "curriculum organization" and "teaching strategies," from Shawna's perspective. The elements included in this component are: (1) local scientific organizations and facilities; (2) materials; (3) science lab technology (for example, motion detector, data collector, and so on); and (4) the Internet. She reported that the knowledge of resources helps a science teacher to efficiently organize her curriculum and to effectively develop her teaching strategies.

She often utilizes laboratory kits developed from local scientific organizations and she and her students visit local facilities in order to allow student to experience science. According to Shawna, knowing many local organizations and facilities related to the science field provides a big support in teaching science (second interview, 5/21/05). In addition to being aware of many resources for materials (for example, activity guideline, lesson plans, and so on), proficiency in the use of science laboratory technology (for example, motion detectors and data collectors) is another required element for being "a quality science teacher" (Third interview, 3/11/05). She also stressed that science teachers need to be able to use the Internet to find information for their lessons.

Shawna's Conceptualization of Seven PCK Components

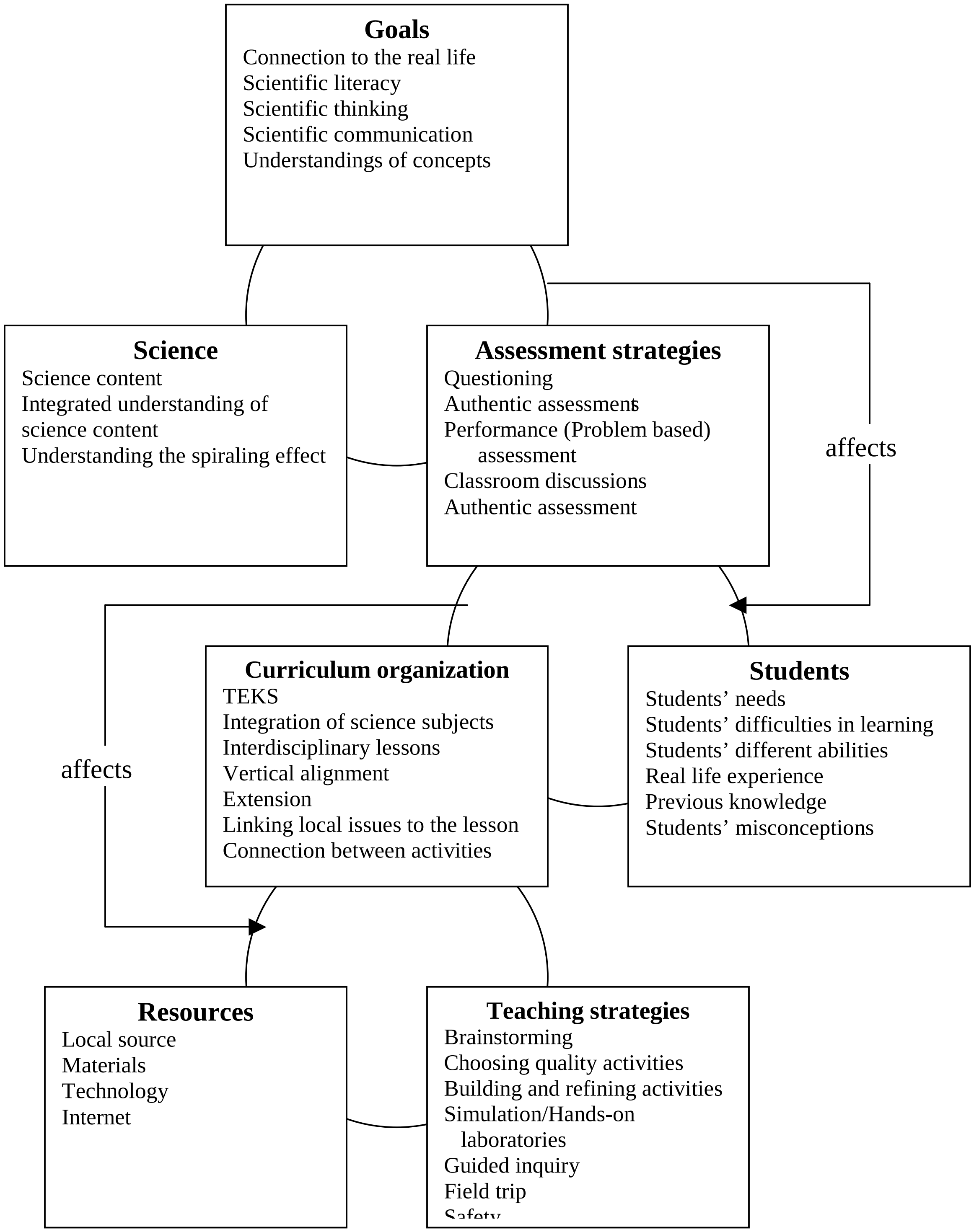
The seven components and their constituent elements that emerged from the analysis of Shawan's data, were reviewed and modified throughout discussions between Shawna and me. She agreed with most of them and further elaborated on the "knowledge of assessment strategies," with only minor revisions of other components. Figure 10 shows her conceptualization of PCK with the seven components. When asked to make connections among the components to show how they are interrelated within the scope of teaching science, she first categorized the seven components into three groups.

The first group includes "knowledge of the goals," "knowledge of science," and "knowledge of assessment strategies." She stated that the first group is the "base" for teaching science. A characteristic of teaching science, as a subject, is determining goal setting and assessment strategies. She put the knowledge of students, knowledge of curriculum organization, and the knowledge of assessment strategies in the second group. Since she uses the idea of "backward design," which builds assessment strategies first and then designs the lessons to prepare students for success in the assessed objectives, she organizes her curriculum based on what to assess and how to assess. In doing so, she considers the diversity of her students and their previously learned knowledge (Third interview, 3/11/05). She stated that the second group is "the content" for science teaching. This second group as a whole influences the third group.

The third group includes "knowledge of curriculum," "knowledge of teaching strategies," and "knowledge of resources." The three components cannot be separated because they interact with each other. She thinks that the third group plays a role as the “process” for science teaching. In particular, this group of knowledge areas determines a teacher’s ability for designing “quality activities” for the students.

When asked to further explain the diagram, she stated, “All seven components are interrelated and influence each other, but some components are more strongly connected to each other. That is why I put them in a group” (Third interview, 3/11/05). She named this diagram “the knowledge components of a quality science teacher” because she thinks that this is compatible with the state’s statement of teachers’ quality.

Figure 10. Shawna's conceptualization of PCK
(The knowledge components of a quality science teacher)



Roger's Case

Roger is the only male participant in the study. The "Teachers as Mentors" project director recommended him for the study, but he hesitated at first to participate because of his busy schedule. After several emails to encourage his participation, he finally decided to join the study. Despite his initial reluctance to be a participant, he was the most accessible teacher among the participants, with regard to scheduling interviews during the data collection period. When I had questions during data analysis, he readily answered by email to further explain what I wanted to know. The more I talked with him, the more I was convinced that he was very competent as a science teacher.

His personal interest in science motivated him to be a high school science teacher (third interview, 3/16/05). After working in the private sector for fifteen years, Roger decided to become a high school science teacher. Roger has a bachelor's degree in Biology and has earned the Composite Science Certification. He also has a master's degree in Education.

He has been working in the high school where he currently teaches for the past ten years, and that is also where he did his student teaching. Roger has been teaching Integrated Physics and Chemistry (IPC) and Geology, Meteorology, Oceanography (GMO) since he started teaching. He is a lead teacher in the Science Department of the high school. Roger has also worked as a TA for a teaching methods course in the department of Science Education at the university and said that it helps him to reflect on his teaching. He serves as a mentor teacher for a beginning science teacher who is working in the same school and also as a mentor for a student teacher. He believes that working with novice science teachers benefits him a great deal (third interview, 3/16/05).

He described himself as a “Jack-of-all trades” because he believes that a science teacher’s knowledge is all encompassing (first interview, 4/30/04). Roger has been active in professional development — such as a mentoring project and statewide workshops — to learn new ideas about science teaching. He used the projects and workshops as opportunities to meet other science teachers and to share useful information with them.

Roger’s Teaching Context

Roger teaches in an urban high school that consists mainly of students from lower income families. The size of the school is approximately 3,000 students. The student body is almost equally composed of Caucasian, Hispanic, and African-American students. Roger has been teaching two courses: Integrated Physics and Chemistry (IPC) for ninth and tenth graders; and Geology, Meteorology, and Oceanography (GMO), an elective course for eleventh and twelfth graders. He teaches five IPC classes and one GMO class a day. He said that these two courses are quite different because of the different grade levels. He also talked about the difference even within the five IPC classes depending on the characteristics of the students in the class. Roger considers this difference as one of the main factors in making decisions for his lessons.

He rarely plans lesson plans ahead of time (as he did in the first years of teaching), but usually teaches "by the seat of his pants" (second interview, 5/14/04). He feels that his class is unique because he allows students to behave freely and take initiative in class. While observing his class, I saw clearly that he had a good rapport with his students (field notes, 4/30/04). He said that he could relate easily to his students because he never grew up himself and this outlook helps him as a teacher (4/30/04, first interview).

His ultimate goal in teaching science is to get students to understand how things work in the world and to use that understanding in their lives. To achieve this goal, he encourages students to learn how to think scientifically in class. He also believes that the nature of science is "inquiry." By his definition, "science as inquiry" means always "wanting to know and using science methods to find out the solutions" (third interview, 3/16/05). Roger wants students to be motivated by effective attention getters, for instance, an eye-catching demonstration or interesting current science event or news. After that, he asks scientific questions and allows students to find the solutions through group activities and discussion.

He believes that students engage in scientific inquiry by following the process, and they learn science as well as the scientific process and scientific thinking. He stated that the activities in his class mirror the real scientific process (first interview, 4/30/05). By allowing students to engage in the process, he anticipates that students will understand in their own way how things work, and will make connections between the science concepts and what they, the students, have done. In doing so, he said, his role is modeling the scientific process, so his students will follow him (third interview, 3/16/05).

While he seeks to use the inquiry process as a strategy for learning science, he constructs his lessons within the standards of the state and district and puts emphasis on knowing science concepts for students to be prepared for the TAKS (Texas Assessment of Knowledge and Skills) test, which is a Texas state standard test.

In the following sections, I will describe his seven components and the elements within each component to form science teachers' PCK, as well as his conceptualization of PCK with regard to teaching science.

Roger's Components of Knowledge for Teaching Science

The components of PCK that emerged from Roger's data are the same as those of other participants, with variations in the elements within each component.

Roger's component 1-a: knowledge of science.

Roger mentioned that "knowledge of science" is the most important knowledge for science teaching. This component includes four elements as follows: (1) science concept knowledge; (2) common sense related to science; (3) scientific process; and (4) current event and issues in science.

When it comes to "science concept knowledge," Roger's belief is that a science teacher should have an expertise in science and understand the concept in depth. He stated:

> A science teacher needs the knowledge of his area and his field of expertise. Then, he can convey so that [knowledge] younger

> kids could understand it. I also think a teacher needs in-depth knowledge of the subject. What I mean is if you are teaching IPC, then as a science teacher you should know more about the subject than what you are teaching. For example, if the concept of the day is Newton's law, then as a teacher you should know all there is to know about force (third interview, 3/15/05).

Roger also stresses the "knowledge of common sense related to science" for science teaching. He explained:

> A science teacher needs common sense about science. That's a big thing because that tells me why a top spins, why a magnet attracts certain metals, why a light turns on. So it starts from very basic concepts and it builds upon that, so you need common sense to understand basic science concepts and real-life situations. It is a beginning and then from that it's all-encompassing (first interview, 4/30/04).

By his definition, "common sense about science" means the understanding of "how things work" in real-life situations. He further explained:

> The common sense is very basic, but if you don't have that, then you have a hard time understanding scientific knowledge. For example, levers. Common sense will tell you that if you want to balance a lever then you have to have the same distance for the same mass on one side versus the other. If you don't understand

> that then I think you'd have a hard time understanding the other principles in Physics. So, common sense first and then you can build on that for Physics (first interview, 4/30/04).

He thinks that science teachers should have specialized knowledge in the subject and also be knowledgeable in the several different areas that they teach.

Roger believes that there is a scientific process and that a science teacher should have an understanding of the scientific process. For example, "questioning," "doing research," and "testing" are included in the scientific process (third interview, 3/15/05). According to his description, the scientific process is equivalent to the scientific method. Each is a logical process for finding the answer to a question or problem. Roger further explained:

> You start with the problem, research for possible answers, try out the possibilities that might answer or correct the problem, make observations to determine if problem is solved. If so, that's great. If not, try another possible solution. It is as simple as trial and error sometimes, and it is as close to inquiry as it gets (third interview, 3/15/05).

He tries to "mirror" the process when he encourages students to do laboratories or activities. Before an experiment, Roger asks students to use their prior knowledge to formulate a hypothesis first, and then to engage in the experiment according to scientific process. He believes that his students learn the science process by being engaging in the experiment to verify their hypotheses.

Another element in this component is to be aware of news and current events in science. One of his strategies is to use the recent scientific event or current news as an attention-getter. He thinks that it is mostly successful. During the classroom observation (5/14/04), he used "electromagnetic rail gun" news from a science journal to draw his students' interest. In an effort to keep up with new development in science, Roger subscribes to several science journals. He believes that this effort helps him to be "a quality science teacher" (second interview, 5/14/04).

Roger's component 1-b: knowledge of students.

Roger ranked the "knowledge of students" component high on his list of relative importance to science teaching. This knowledge helps him to understand how his student learn, which is how he is able to decide how to teach (third interview, 3/15/05). This component includes a variety of elements: (1) students' interest; (2) students' weaknesses and learning difficulties; (3) students' misconceptions; (4) students' different levels; and (5) students' different ways of learning.

When he considers his students' interests, the lessons and activities he teaches are more likely to be successful. Therefore, he tries to establish a good rapport with his students in order to understand their interests better. Roger said, "When I see an interest in the students, the lesson tends to make it easier to teach" (second interview, 5/14/05). He also assesses his students' understanding from their responses during the lesson. When he gets the feeling that the students are having difficulty understanding specific science concepts, he tries to modify his lesson. This process happens during his teaching, which is why he does not spend long hours planning lessons ahead of time.

He recognized from years of teaching experience that students' weaknesses and misconceptions about specific units are repeated every year. He often considers those misconceptions prior to his lesson and tries to explain the concepts, if necessary (second interview, 5/14/04). Another element that he emphasizes is to "considering of students' different levels." It is necessary to have different modes and methods for dealing with different levels of student ability (first interview, 4/30/04). Finally, in his lesson planning process and during his lesson, Roger considers the different ways that students learn. When asked to further explain why, he stated:

> You can't talk in terms that you learn in college to the students, so a teacher should know the different ways that students learn. It's not just getting up there and lecturing all period long. You've got to have some pictures of them. (first interview, 4/30/04).

Roger's component 2-a: knowledge of goals.

According to Roger, this component is "what I want my student to gain" in class (third interview, 3/15/05). This component is composed of four elements: (1) applying scientific concepts to everyday life; (2) students' scientific thinking; (3) understanding how things work; and (4) scientific literacy.

He believes that teaching is most effective when students relate what they learn to their own knowledge and experience, and vice versa (second interview, 5/14/04). To incorporate this belief into his class, he usually uses materials that are easily found in daily life. For example, Roger started the “electricity” unit as follows:

> R: Electricity has a very large influence on our lives, but it is not well understood by many people. Electricity is used to power many of the things that we use every day. What are some of the things that use electricity?
>
> S: Television, computer, microwave, telephone…
>
> R: Just looking around, it is not too hard to come up with some examples on your own. Since we can’t think of living without electricity, you need to know something about it. So, this unit will introduce you to some of basic facts about electricity and electromagnetism (observation, 5/14/04).

After that, he took out a bulb from his drawer and put it into a microwave in front of students. He asked the students, “What would happen if I turn on this microwave?” The students responded, “You can’t put a light bulb in a microwave!” When I interviewed him after the lesson, he said that this type of question prompts students to think scientifically. According to Roger, scientific thinking is one of the goals that he want his students to gain in his class.(second interview, 5/14/04) He believes that students are able to understand how things work by scientific thinking, and he expects his students to learn how to think scientifically in his class (first interview, 4/30/05).

In addition, Roger tries to develop lessons aiming at "scientific literacy." He stated:

> Science touches the lives of everybody without [them] even knowing it. You can't go through life not knowing how things work. "Why does a light bulb light when the microwave's power is on?" "Why does ice float?" Those are certain things that you've got to have some sense about in order to raise a family, or in order to know how to mix some medications, or cook a dinner or any of that stuff. So, science is basically in every aspect of somebody's life. You can't go through life not knowing about it. (second interview, 5/14/04)

Roger's component 2-b: knowledge of teaching strategies.

Roger recognizes "knowledge of teaching strategies" as a tool for conveying science knowledge and for achieving the goals of the lesson. This component consists of four elements: (1) an attention-getter; (2) various teaching methods; (3) selecting effective activities related to the concepts; and (4) being flexible

Roger tries to use an attention-getter to engage his students in the lesson. He stated, "My strategy is to start the class off with an attention-getter. So I always try to come up with some demonstration or some current event" (second interview, 5/14/05). When he sets specific lesson plans in the unit, he uses at least one attention-getter related to the topic for each lesson (first interview, 4/30/05).

He found that the lessons tend to be more successful when the attention-getter works. Since students may not respond as expected, he stated that a teacher should prepare various methods for teaching a lesson.

When asked about how he got to know a variety of teaching methods, he responded, “Trial and error. Going to workshops. Certainly getting my degree in Education gave me a lot of different ideas and gave us various methods on how to teach science” (first interview, 4/30/05). He also reported that he holds onto teaching methods when they turn out to be effective. Roger said:

> I will first try it and if it works, I add it to my toolbox. If it doesn’t, then it winds up getting pushed aside. And I try another thing. So, trial and error — and determining from that, which works best and which doesn’t [work] (first interview, 4/30/05).

According to Roger, given the different levels of students, a science teacher needs to know various teaching methods. He stated, “Everybody has different levels, so you have to have a lot of different modes and methods of doing that, so a large supply of resources and methods of transferring that information” (first interview, 4/30/04).

In addition to knowing a variety of teaching methods, science teachers need the ability to select an activity, which is another element within the “knowledge of teaching strategies.” He stated, “You [science teachers] should select what you are trying to convey and what activities you can do with it — either hands-on or visual.

So, you need to look at the whole spectrum of possibilities" (first interview, 4/30/04). In the second interview (5/14/04), he also stated:

> Not to say that labs are the best things all the time to use. I am beginning to think that a science teacher really has to choose his or her labs wisely. Otherwise, the amounts of time they [students] consume versus the content that they [students] pick up are not efficient. And just because a science teacher is supposed to have forty percent lab time doesn't mean that you are getting the best teaching out of that. I think it's best to really look at the subject and then decide, "Is it going to be better with lab or just basic teaching methods: lecture, notes, and book work?" (second interview, 5/14/04)

The last element within this component is flexibility. What this means is being able to adjust one's lessons or activities according to students' responses. Roger thinks that teaching practice is often different from lesson planning, so he does not spend a lot of time setting up lesson plans. He stated:

> I spend a lot of time setting up a weekly lesson plan and at the end of week, I look back and I say, "I am not even in line. I've gotten off track. I've wasted all this time trying to set up a plan." But you can't plan how a lot of this stuff is going to turn out. As far as writing out an entire week or month, I find that's difficult to do. I do change plans and activities, even during the lesson. It depends

> on how my students respond or how are the supplies available. So, I think being flexible is very important to a science teacher (first interview, 4/30/05).

The sources from which Roger has acquired "knowledge of teaching strategies" are workshops and further education in an advanced degree. He also expands this knowledge by observing other teachers.

Roger's component 3: knowledge of resources.

According to Roger, this component affects teaching strategies. This component includes four elements: (1) local facilities and organizations; (2) materials; (3) activities; and (4) science magazines.

He often visits nearby local facilities for field trip with his students. For example:

> Next week, we're going to Dos Rios Reclamation Facility, where they show the raw sewage coming in and going through the processes and coming out into the Medina River. So, they [students] will be seeing that. So, we are looking at wastewater. And actually we're in Meteorology, so we are studying what happens to the water that hits the ground, the runoff, and the water cycle (first interview, 4/30/05).

Roger thinks that field trips allow his students to learn about the function of local facilities and organizations and make connections between what they learn and their real lives.

He also researches materials and activities for his science lessons and keeps collected materials and ideas about activities or lessons on his computer for future use. As mentioned earlier, he uses current science news as an attention-getter. Therefore, he subscribes to several science magazines and collects articles for his lessons.

Roger's component 4: knowledge of assessment strategies.

Roger's main assessment strategies include quizzes and examinations because he believes that understanding basic concepts is required to achieve his goals for the class. This component includes: (1) benchmark tests, (2) questioning, (3) follow-up laboratories, (4) allowing students to grade their lab work (student self-assessment), and (5) immediate feedback.

> Roger usually starts his class with a "benchmark test" to monitor students' prior knowledge. This test helps him look at students' weak areas. He also uses oral questions because this allows him to visualize what students understand in the lesson (first interview, 4/30/05).

Another part of Roger's assessment strategy is the "follow-up laboratory," which means having students do laboratory activities that apply what they have learned (third interview, 3/15/05). Since these are open activities, his students have to come up with the ideas, do the experiments, and draw conclusions by themselves. Roger also allows his students to develop their own criteria for grading their lab work. He thinks that the students are able to grasp the core ideas while developing their own grading rubric.

Given that the purpose of assessment is to help students' learning, Roger said, a science teacher needs to give immediate feedback on students' work. He believes that this skill is required to be a good science teacher (third interview, 3/15/05).

Roger's component 5: knowledge of curriculum organization.

The last component that emerged from Roger's data is "knowledge of curriculum organization." He stated that a solid "knowledge of science" supports this knowledge area. He reported that the level of his knowledge is not as proficient as he would like because he does not spend a lot of time setting lesson plans. He usually follows his instinct and makes a decision what to teach in the subsequent lessons based on how students respond to a particular lesson. This component includes five elements: (1) TEKS; (2) TAKS; (3) district standards; (4) expanding on a concept; and (5) making connections between concepts.

Roger decides "what students need to know" based on TEKS and TAKS, saying:

> I think that the textbooks have so much in there. There is no possible way you could teach them to your students. We are given a set of standards, TEKS, to have them learn so they can pass the TAKS test which is almost important to get them to learn that in the period of time. So, it's very important that we pick out just exactly what we need and try and teach it (first interview, 4/30/05).

He also relies upon the district standards to organize curriculum because they are more specific. He reported:

> District standards are given to us and that pretty much outlines what we need to teach and that is reflective of the TAKS. We also have benchmark tests that come up at particular time frames. It is TEKS-related. It's a test to allow the teacher to see if they are meeting the standards put out by the district and where their weak areas are as far as the teacher just by looking at whether the students were having success or no success (first interview, 4/30/05).

Additionally, he reported that participating in professional development workshop is important because he often gains the ability to make a decision about what to teach and how to select from among them(second interview, 5/13/04).

Roger reported that he usually starts to get students to understand simple concepts and then move to more complex concepts in order to expand upon those basic concepts. For example, he said, "They really get an idea how the magnetic field leaves one end and then rotated to the other side. And then, I talk about earth's magnetic field" (second interview, 5/14/04). Given that there are a lot of interrelationships among different science concepts, Roger also thinks that a science teacher needs to know how to make connections between the lessons (second interview, 5/14/04).

Roger's Conceptualization of Seven PCK Components

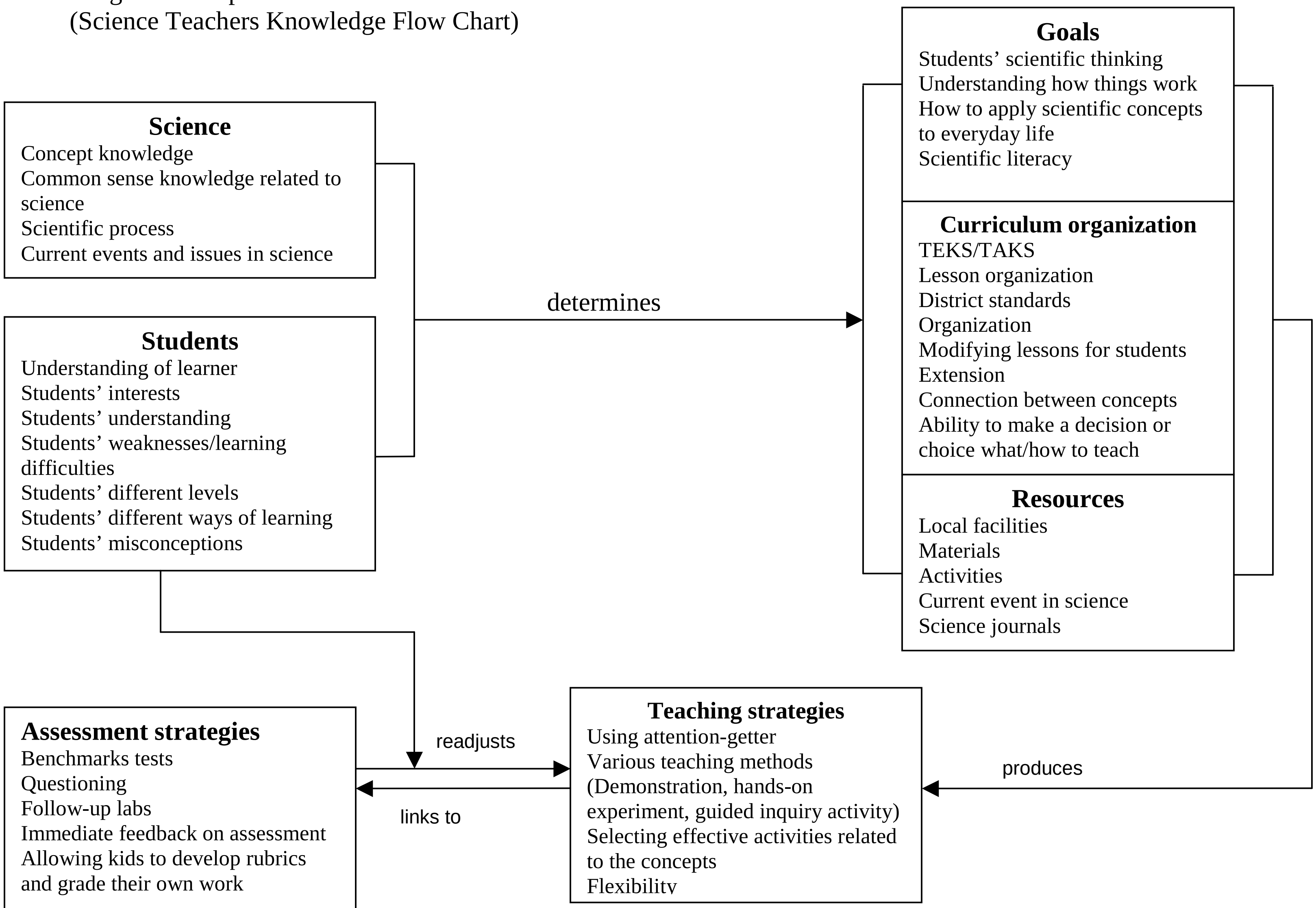
The seven components and elements that emerged from the analysis of Roger's data, were reviewed and modified several times — due to the discussion between Roger and me — and he added a couple of elements to some components during the final interview. After this process, Roger agreed that these seven components form a science teacher's knowledge for teaching science. He then drew a diagram showing how the seven components are interrelated within the practice of teaching science. His conceptualization of PCK is shown in Figure 11.

Roger stated that having solid science knowledge is the most essential part of teaching science. He thinks that this component of knowledge is a driving force behind teaching science. Along with "knowledge of science," he reported that his understanding of students is the other important part of teaching science. These two components determine "what his class is aiming at" (goals), "what to teach" (curriculum organization), and "where to look for activities and information" (resources). He put these three components in a group because all are determined by the "knowledge of science" and "knowledge of students." Of these three components, "curriculum organization" is influenced by "goals," as well as by"resources ."

The three components mentioned above, as a group, produce "how to teach" He reported that his teaching strategies rely heavily upon "resources." He also thinks that "knowledge of teaching strategies" is linked to "knowledge of assessment strategies," because he usually develops his assessment methods based on how he taught the lesson. In doing so, he also often comes up with an idea of "how to teach." Therefore, he thinks that these two components are tied to each other. He also addressed the needs for readjusting teaching strategies according to students' responses.

When asked to title the diagram, he named it “science teachers’ knowledge flow chart.” He usually finds that this routine happens in his science teaching practice, regardless of the specific topic being addressed.

Figure 11. Roger's conceptualization of PCK
(Science Teachers Knowledge Flow Chart)



Emily's Case

Emily is the fourth participant in this study. The "Teachers as Mentors" project director has worked with Emily in a couple of projects for more than five years. She identified Emily as an exemplary and student-centered middle school science teacher and recommended her for this study. Emily was very busy, due to her being a participant in several projects for professional development. She was also serving as a teaching assistant for an instructor of a Chemistry course at the university. The course instructor, who serves as one of the instructors for the "Teachers as Mentors" project, also recommended Emily for the study. This Chemistry course was one of the required courses for completing the master's degree in Integrated Science at the university. She has earned her master's in this program and she is currently assisting in experiments and activities in this course.

As the study progressed, she moved from middle school to high school, which kept her busier and unable to reply to my emails. Although she readily gave me her consent to be a participant in the study, it was really difficult to set an interview schedule and the interviews were mostly conducted after school in her classroom or before her class at the university.

Emily had been seeking a degree in the Accounting program for two years at college, but she did not finish. After that, she got a job as a special education paraprofessional at another middle school. While working in the middle school, she decided to go back to college and get her degree to teach science at the age of thirty years. She earned a bachelor's degree in Biology and Chemistry and was certified in

Biology and Chemistry for high school. She also took the Examination for the Certification of Educators in Texas (ExCET) in Life and Earth Science. She then earned her Master's degree in Integrated Science at the same university. As the study started, she was teaching in a middle school, but has now moved to a high school.

She believes that one of her strengths as a science teacher is her enthusiasm: "My enthusiasm and love of science just came naturally. I have been interested in science since I was twelve and I wanted to be a geologist. I got sidetracked, but I have always loved science" (first interview, 12/03/03). She also characterized herself as a science teacher with a strong background both in science and education. She said:

> The strengths of knowing my background knowledge came from my education at the university. The university prepared me for this and it was hard. The professors were hard on us and they kept demanding better and better and I think that is a very important thing with the teacher preparation program. So, I think it is that demanding preparation program that got me ready for what I do (first interview 12/03/03).

The following sections provide more detailed descriptions about her teaching environment and her approaches; the components which emerged from her data; and a representation of her PCK conceptualization.

Emily's Teaching Context

When this study started, Emily was a middle school teacher. She had taught in the same middle school in downtown San Antonio for thirteen years — ever since she began teaching science. She reported that most of her students are from low income families (second interview, 5/20/04). The majority of students in the school are Hispanic (50%), with an equal number of Caucasian (25%) and African-American (25%) students. She has taught all grade levels in the middle school. The year that she joined this study, Emily was teaching four classes of seventh-grade science and two classes of six-grade science. Of her four classes of seventh graders, two of them were pre-AP classes (comprised of honor students), and the remaining ones were regular science classes. She designs her teaching strategies for her pre-AP classes differently from those for the regular classes. She tries to pull her students to higher levels and give them a more enriching experience. She also commented that one of her sixth grade classes has “resource kids,” students with learning disabilities. Nonetheless, she believes that she can get the students engaged in learning science through well-developed activities (first interview, 12/03/03).

Emily said, “My weakness as a science teacher is that I get frustrated with the politics and I lose patience with the politics because I don’t see the purpose of the politics” (first interview, 12/03/03). She expressed that the paperwork related to the politics bothers her. She also stated that one of her weaknesses is that she easily gets sidetracked because she is so eager to answer the students’ questions and to explain further. That can pull her away from what she is supposed to be doing. For this reason, she does not write her lesson plans in advance and she rarely plans how the class goes because her class may speed up or slow down in relation to student interaction.

Emily tries to be sympathetic to her students. When she thinks that the lesson or activity is boring, she believes that her students would be bored also. She said that she is able to tell this from her gut reaction, an instinct that comes from her years of teaching experience. She believes, therefore, that science should be considered a verb (that is active) versus a noun (that is passive). She said, “Science is not just a subject. It’s a verb. You have to do science. You have to experience science. If you just read about science, you are not learning anything about science. They have to feel it. They have to have the science first.” (first interview, 12/03/03) To make students do science, she usually starts her lesson with some focused questions that allow her students to concentrate on science ideas. She wants her students to engage in the scientific inquiry process, because she thinks that her mission as a science teacher is “to help every student believe that they can think like a scientist, act like a scientist, and be a scientist” (second interview, 5/20/04).

She mainly learns new teaching strategies from professional development workshops. She considers the workshops as opportunities to share information with her colleagues on what they have done in their classes. She does not want to repeat the same lessons every year, so she is really active in her professional development (second interview, 5/20/04). She is also very active in sharing the lessons that she developed and in asking for feedback from other teachers at either nationwide or statewide workshops. As a matter of fact, the “Teachers as Mentors” project director valued Emily’s efforts and enthusiasm in this regard and recommended her for this reason.

Emily was very expressive in presenting her ideas and beliefs about teaching science and these characteristics helped me to accurately understand her conceptualization of PCK. In the following sections, I will discuss the components that came out in the interviews with Emily and how she conceptualizes PCK related to teaching science.

Emily's Components of Knowledge for Teaching Science

The same seven components that emerged from the analysis of Emily's data were the same ones identified in the others' cases. When asked to rate the components according to their relative importance in teaching science, Emily classified the seven components into three groups. In the following subsections, each component is described including examples based on her rating.

Emily's component 1-a: knowledge of science

Emily rated the "knowledge of science" highest, in that knowing what you teach is fundamental in order to teach. This component contains the following three specific elements: science content knowledge, scientific method and process, and the nature of science.

Emily stated that the confidence of a science teacher is directly proportional to her science content knowledge. In this regard, She was convinced that her strong science background made her a good science teacher. She stated:

> My strength is my background knowledge in my subject, because I came with a bachelor's degree in biology and chemistry. When I started [teaching] Integrated Science in middle school, it was kind

> of scary because I did not have a background in Geology and Astronomy. My Physics was kind of weak so that's why I decided to go back and get the master's in the Integrated Science — to make myself strong. Now when my students ask me a question, I feel confident that I can either, well at this level, it's pretty much easy to answer whatever question. If things are tough, I know exactly where to find answers. My strength is my science background and the strength of knowing my background knowledge comes from my education at the university (first interview, 12/3/05).

According to Emily, a science teacher should update and upgrade his or her science content knowledge because science knowledge is changeable. She usually does that by participating in professional development workshops (second interview, 5/20/04). She also admitted that a science teachers' science content knowledge is different from that of scientist. She said, "a science teacher has many branches of knowledge within science. Some of them might be very specific while some of them are more general and broad." (first interview, 12/3/03)

This component also includes knowing the scientific method and process. Given that science facts, laws, and theories are produced by scientific method and process, Emily states that understanding of the scientific process is necessary for grasping science knowledge. She thinks that her teaching strategies are related to the discipline of science. Most activities in her classes are designed to promote students' "inquiry" by following the scientific process (first interview, 12/03/03). She said:

> My science class is unique because of the inquiry, the exploration. Because it's kind of funny for a lot of kids, they think that — somehow — when the scientists go into a lab to study, there is a blueprint that they follow. They don't understand that scientists have to be, have to brainstorm, have to think, have to pull on their prior knowledge, their interest, their ideas, the needs and then from there [they] develop their experiment. So, I think that my lessons follow that somewhat (first interview, 12/3/03).

Emily's students learn the nature of science by engaging in activities that incorporate the scientific process. For this strategy to be successful, she thinks that a science teacher needs to understand the nature of science. According to Emily, science is not always true; it needs evidence to explain it, and she tries to incorporate this idea into her lessons. In accordance with this belief, she accepts any results of laboratory work if students can logically explain them. Emily thinks that it is a part of the science process, saying:

> When we do labs, if the results come out wrong, it's so hard for the kids. So, they'll try to change their results section, and I tell them "No, you should report what happened. And I tell them, "Remember — in science — this is the only place where you're allowed to be wrong and still get 100 percent. If your hypothesis is wrong, that's okay. We'll go back and retest. We'll go back and redo. They [should] do labs like scientists; they [should] go back if

> they have to redo it. They often come up with a new problem. Sometimes there are new questions from what they get from the lab and that's what we do (first interview, 12/3/03).

Emily's component 1-b: knowledge of goals

Another component of PCK is "knowledge of goals." According to Emily, the subject that a teacher teaches determines the "goals." Therefore, this component goes with "knowledge of science" in that sense. She defined this component as "what is the most important thing that you want to come away with, besides TAKS test" (third interview, 3/23/05). This component includes three specific elements: integrated understanding of science concepts, real-life application, and scientific literacy.

Emily believes that, above all, students should understand scientific concepts and how the concepts are integrated in order to apply their knowledge to their lives (second interview, 5/20/04). In order to boost students' integrated understanding, Emily often encourages student discussion. She stated:

> We do labs and then we come back and discuss again. First, we look at back at what the lab was or how we did it, and then as we move through the body systems, the kids started realizing — well, you can't talk about one body system without talking about the body, all body systems that work with that one — and by the end of the unit they realize that the human being functions as one whole. So you look at the system through its parts, but then coming to an

> understanding and "aha," that there is a whole and you can't really just separate them out (second interview, 5/20/04).

Another element within this component is "real-life application." Emily believes that a lesson is successful and that she has achieves her goal for the lesson when students are able to apply the knowledge to their real lives. For example:

> When we first started with the levers and pulleys, it's really neat because the kids are given the materials and they are given some basic questions. You know you put a clip here and if you put the box here and then they start thinking about how to make a lever work. Then they start exploring and they move into moving the load closer to the floor, moving it farther away and that moment of "aha," and then they start saying things like "Oh, Miss, I always wondered why they have the handle on the hammer so far away from the head of the hammer. Oh, now I understand why the longer the screwdriver, the better it is. Now I understand…" And so they start pulling these things into their real lives. I think [it was] the success (Emily, first interview 12/03/03).

Accompanying these two elements, "scientific literacy" is also included in this component. When asked about her ultimate goal for her science classes, Emily stated:

> The main goal that I want my kids to develop is a love of science and to believe that they are scientists and that every time they ask a question, they are acting like scientists. When they go into their

> homes and they are around the neighborhood with their friends and they say, "I wonder why …" That's because they are thinking like a scientist. That's my main goal. I mean that it's right there in my mission statement. My mission is to have every student to believe that they can think like a scientist, act like a scientist, and then be a scientist (second interview, 5/20/04).

As her mission statement clearly shows, she expects her students to be scientifically literate by asking questions and thinking and acting as scientists do.

Emily's component 2-a: knowledge of students

Five specific elements that emerged from Emily's data are grouped into this component: (1) students' different levels of understanding; (2) different abilities of students; (3) different interests of students; (4) different needs of students; and (5) prior knowledge of students.

Emily determines her teaching pace and strategies based on her students. When asked about the primary factors that she considers when planning and teaching a lesson, she stated:

> I have to go with what kind of students I've got. What are their ability levels? What are their interests? From there, I might make plans. But, I seldom — I write my lesson plans in advance but rarely does it follow that flow. Things may speed up, slow down. (first interview, 12/3/03).

Emily also stated, “I have different classes of different ability levels and different needs, so I need to consider that” (first interview, 12/3/03). According to Emily, it is also important for a middle school science teacher to construct her lessons based on students’ interests because those lessons tend to more successful in engaging students in the learning process. She strives to meet these differences when she teaches. She said:

> I think that something is changing in the learning style of students and that means that we have to think about, because we need to adjust our teaching practices. If there’s change in the way they learn, we need to figure out what it is and then change to meet how they’re learning (second interview, 5/20/04).

Emily also considers students’ prior knowledge. To informally assess the knowledge her students have previously acquired, she usually asks questions. She reported:

> I often use questioning to pull from them because these kids do have a lot of background knowledge already. They just don’t realize it. They don’t know how to channel it. And then — once we get to that — then, it’s “Oh, Okay”, “Uh huh.” (second interview, 5/20/04).

Emily’s component 2-b: knowledge of curriculum organization

This component includes six elements that emerged from Emily’s data. Those elements are: (1) TEKS; (2) organizing integrated science lessons; (3) making connections between concepts; (4) vertical alignment; (5) aligning with other subject areas; and (6) being flexible.

Like the other participants, Emily uses state standards — TEKS — as the main criterion for her curriculum organization. In addition to understanding TEKS, the ability to organize integrated science lessons is also important to middle school science teachers. Emily stated:

> I like to start with Chemistry and Physics; and then it's basically what I think of as a logical flow because the TEKS in the middle school — it's okay. But, here's a chunk, here's a chuck here, and they pull from all different areas of science because it's integration. The trick is weaving that thread to pull them together. So, I've developed my own progression of what that thread is and basically what I do is I start with the Chemistry and Physics, then after that I start out in the universe and I pull it down to inside the human body. So, I start with the bigger picture — astronomy, weather — and then down to our earth — our planet, geology, that kind of stuff — and then down even further to animals and the humans and trees and everything that lives on planet, down to what are humans made of (second interview, 5/20/04).

Making connections between concepts is another skill required for being a good science teacher. Emily looks at students' learning from the constructivist's perspective. She stated:

> I think about this concept and what we'll build after it. I also think about relating to past concepts. For instance, like my kids are learning levers and pulleys now. We studied in the spring the human body and we start talking about the skeleton system and the muscular system and I hope to help them understand that within the human body there are levers and pulleys, too (first interview, 12/3/03).

Emily also considers vertical alignment while organizing curriculum for her classes, because she thinks that middle school science is a foundation for high school science. For example, she stated:

> This unit is important for my students because it sets the foundation for high school biology, [which] they must have, and also it's part of the TEKS 7.9A. This unit covers the TEKS and it is very, very important for them, so that they can have an understanding to do well in high school biology class (second interview, 5/20/05).

Another element that Emily incorporates into her curriculum organization is alignment her lesson with other subjects. She believes that students' learning becomes more meaningful through such alignment. For example:

> I was getting ready to move into the cell. That's why I was looking at some information and I found out that the social studies teacher on the team was going to do things about atmosphere, weather, things like that. And, in social studies, they just touch on it, but I

> was like, *Oh, wow! If that's the case, then I am going to do all GLOBE atmosphere with sixth grade and the stuff that's in the book and pull out the barometers and things like that*. And so he and I met the other morning, and I said, "Well, I teach about this," and he said, "Oh, great! Because I teach about this other part." Like he's going to really focus on air pressure but I am going to focus on barometric grid and what do they mean and how can you measure, and so on. So, by doing that, the kids are going to be reinforced from two different teachers, two different viewpoints. So, collaborating with my other teachers that helps me to reinforce the children's learning (first interview, 12/3/05).

The last element in "knowledge of curriculum organization" is "being flexible." Emily reported that she builds up her lesson based on students' response rather than depending on a solid lesson plan. She stated:

> I am constantly planning my lessons because I think it comes with the experience and with time. You get to the point where — as you are delivering the lesson or your students are engaged in a lab — you are constantly assessing what's going on and I can't tell you how many times that from day to day, I've changed my lesson. This week was an example. My kids just weren't getting the difference between a second and third class level. And I'm watching them going through the lab and I'm watching them manipulating and

> asking each other questions and I could see the looks on their face and I am thinking, "Oh, you know what? We can't move on." Tomorrow, instead of doing what I was planning, I am going to do blah, blah, blah. So the planning portion takes place all the time. There's not a time that I sit down and I say, "Okay, it's Thursday afternoon. I am going to sit down and plan my lesson. That's not what happens. For my year, I have a skeletal frame for the year (first interview, 12/3/03).

Emily also readjusts her curriculum based on students' input. She stated:

> I might have a student say, "Hey, Miss, I have this, I saw this really cool thing. Can we build it?" or "Could we investigate it?" or "Could we do it?" And, I will ask the other kids, "Are you interested in that?" "Yeah." So we might get side tracked and do something else for a little while. So, my lesson planning is continuous. It just never stops (first interview, 12/3/03).

Emily's component 3-a: knowledge of teaching strategies

Based on the results of Emily's data analysis, "knowledge of teaching strategies" includes several specific elements, including scientific inquiry, a variety of activities, and Cornell note-taking.

Emily thinks that science teachers should help students learn how to do inquiry in their classes, and she believes that this makes science different from other subjects. She says:

> I don't believe in cookbook lab. I don't believe in kids coming in and receiving the lab, this is step 1 and this is step 2, fill it with water. I would rather my students develop an idea. I might give them the problem but they have to think everything through — what they are going to do — and that's what a scientist does (first interview, 12/3/05).

When asked to define "inquiry," she said, "If it is an inquiry lab, students have to think it through and pull it through" (second interview, 5/20/04). Emily prompts students to generate questions in order to engage in scientific inquiry process by themselves. For example:

> I had this box up there that's just filled with all kinds of different, little cheap toys and in this lab what they have to do is they have to, I mean, *really* focus. I give them a few minutes at first and it's crazy. It's loud in here when they do it. Let them just play with it. They are children so they can play. And then they have some very focused questions; "How do you make this car move?" "How do you make this toy move?" "What do you have to do?" "How can you make your toys go faster or slower?" What it does is, it really focuses. It makes the kids focus on what I am trying to pull out of them internally without even introducing it at first. It is the idea of force. And from that — and they will come up with the push, the pull, the idea like that. And what they are doing is they're actually

> giving me the definition before they ever give me the vocabulary. That's another reason why I love the FOSS kits so much — like we're doing levers and pulleys right now — is because it pulls that from the kids. It engages and it pulls them. It makes them think (first interview, 12/3/03).

She also believes that there are many alternative ways of teaching a concept, and that a science teacher should consider his or her students and available resources in order to select the best teaching strategy for a lesson. The following quote shows her underlying assumption in making decisions about her teaching strategies:

> Science, you can get science out of a book. Science is not just a subject. It's a verb. You have to *do* science. You have to experience science. If you don't, if you just *read* about science, you are not learning anything about science. You may be getting some background information, but — I mean — I could have my kids read all day long about levers and pulleys and look at pictures and everything but my kids would not have been able to relate. They had to *feel* it. They have to have the science first (first interview, 12/3/03).

Emily also listed Cornell note taking as one of her teaching strategies. She further described:

> "Cornell notes" is a style of note taking developed by Cornell University and basically what you do is you do your note taking on

> the right hand side. You fold your paper and you do your note taking on the right hand side. After you take your notes on the left hand side, you develop your own study questions. And then that helps you get ready for tests or pre-labs or whatever because you have your own focus questions. And, because it was developed by you, it is a more internal thing. It's more meaningful, and then the kids hold on to it (second interview, 5/20/04).

Emily often uses these questions developed by students as a springboard for student discussion. By doing so, she connects her teaching strategies with assessment strategies.

Emily's component 3-b: knowledge of assessment strategies

Emily stated that assessment strategies are intertwined with teaching strategies, in that "what and/or how to assess" should be considered based upon "how to teach" in order to achieve the goals for her lessons (third interview, 3/23/05). This component includes the following three specific elements: various strategies of assessment, "how" types of questions, and laboratory journals.

Emily uses a variety of assessment strategies to examine students' understanding either explicitly or implicitly. She also believes that a science teacher should perform ongoing assessment to help students understand of science concepts. When asked how she determines whether students understand, she said:

> There are several different ways that I do it. I do teacher observation, walking around asking the kids, questioning and

> checking their responses — checking for understanding. My kids know that the lab conclusion is an integral part. If I don't understand it, I tell them, "If you don't do a good conclusion, then I don't think you really know it and you need to learn it. You need further understanding. The way that scientists express themselves is through their conclusions. So, I am kind of forgiving for other parts of the lab report, *except* conclusion. To me, it's the summary and it's the test. So, I look at the conclusions very hard because lab conclusions are a big part of how I analyze them [the students]. We also have question and answer time and review sessions near the end of class or at the end of each activity. At the end of each unit, I either give TAKS or other tests, or I give kind of a hands on laboratory assessment type. For instance, today I had them investigate different toys and decide whether they were first, second or third class levers and they thought they were just going to another lab. What I was doing, it was their test. I just don't tell them it's a test (first interview, 12/3/03).

One of Emily's favorite ongoing assessment strategies — that also happens to be very effective in determining whether to adjust a lesson — is "how" types of questions, such as, "How do your body's systems interact with each other?", "How does your body use food?", "How can you receive blood from somebody else?" (second interview, 5/20/04). Emily reported that she can confirm students' understanding based on their explanation of the responses, while students have a chance to reflect on what they have learned. She said that both she and her students benefit from this form of questioning.

Another assessment strategy is to use students' science journals. She thinks that this assessment strategy helps her to achieve her teaching goals. She stated:

> A scientist has to be disciplined and accurate in how they report their data and I am very specific with them. Use unit. Do your graph properly. I make them use composition books because that's what I used when I was doing research. While they are doing this, they reason why and I used this in research, too, because the pages are sewn in — you can't lie or fudge when you are a scientist. You are recording your information, you date them, you time them, everything that you have page by page. With my students, I feel that this is a cheap way to put [into practice] a tool that is really used by a scientist. If you make a mistake, you don't rip out the page. Mistakes are part of science. You can just put an X through the page, move on to the next. So, it really teaches them that this is how scientist works in the real world (first interview, 12/3/03).

Emily's component 3-c: knowledge of resources

As other participants addressed the importance of knowing resources, Emily also reported that knowledge of resources facilitates lesson planning and teaching practices. This component includes three specific elements: information on activities and materials, multimedia, laboratory technology, and campus resources.

Emily usually gains information on activities and materials that she can apply to her lessons by participating in workshops. When asked to further explain this, she reported:

> It comes from professional development, especially all the professional development I received at the Lake University. It helps me to learn new strategies and new activities that are coming out. We also share this information. I like pulling in other different things because then I don't get bored. (second interview, 5/20/04)

She also reported that knowing how to use multimedia is useful in effectively presenting science content. She also makes an effort to use as many types of laboratory technology equipment as possible. She thinks that this generation of students needs to know how to use these instruments in order to be scientifically literate citizens of the future.

Another element within "knowledge of resources" is "campus resources." According to Emily, she is unable to plan laboratories and activities in her science classes without this specific knowledge.

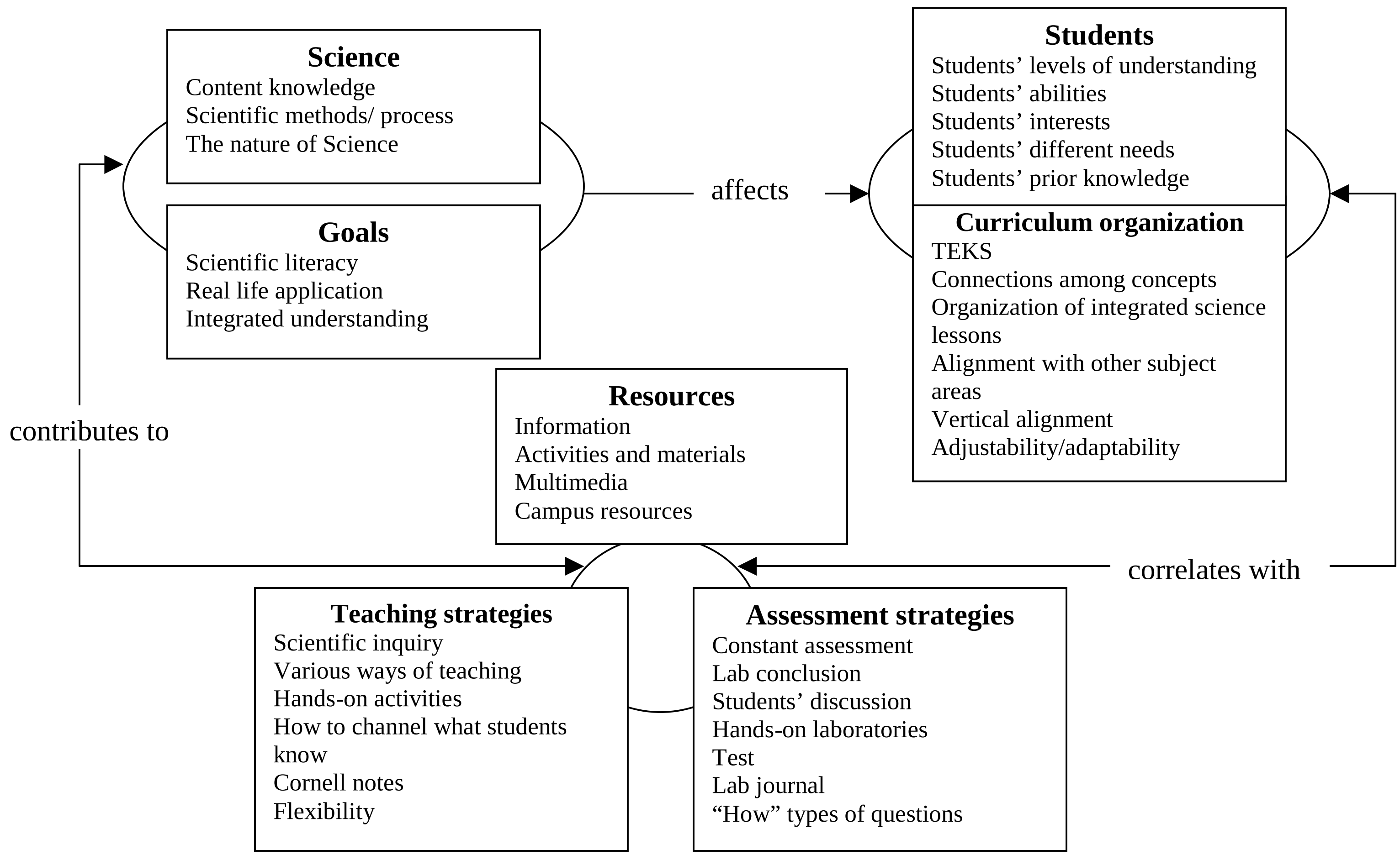
Emily's Conceptualization of Seven PCK Components

Emily agreed upon the seven components and elements, with the addition of a couple elements within "knowledge of resources." In the third interview, she was excited about seeing the visualized knowledge components that had emerged from her data. When asked to show how the components are interrelated within teaching science, Emily first categorized the seven components into the three groups and then drew linking lines between groups (Figure 12).

According to Emily, “knowledge of science” and “knowledge of goals” are attached and these two components are the “object” in teaching science. Students and a teacher’s curriculum organization are influenced by these two components. She also compared “knowledge of students” and “knowledge of curriculum organization” to the “subject” within the situation of teaching. These two components are the factors that determine how to teach (teaching strategies), what to assess, and how to assess.

Emily put the remaining three components — “knowledge of teaching strategies,” “knowledge of assessment strategies,” and “knowledge of resources” — into a group that indicates “methods” for teaching science. She believes that the last group, named “methods,” helps her to achieve her teaching goals and helps her students to make sense of science content.

Figure 12. Emily's conceptualization of PCK
(Knowledge Components for Science Teaching)



Part Two

Seven Components of PCK

The seven components that emerged were common to all four participants. Whereas the seven components for each case were described in detail, it is necessary to look at them across the cases. Although these seven components are thought to be knowledge areas of teaching science, the result of this study clearly shows that they are actually components of PCK which is more specific. I also need to address that I drew upon the terminology — PCK — in a generic sense, which means that the knowledge is necessary for teaching science in the secondary school setting.

In the following paragraphs, each component of PCK is summarized with a couple of salient quotes.

Knowledge of Science.

Most teachers emphasize “knowledge of science content” as the primary knowledge area for science teaching. For example, as Roger stated:

> Being a science teacher, science knowledge would be very important. If you are a Chemistry teacher then you would definitely need knowledge in the Chemistry field. You would also need to know how it applies to biology or other science areas and how to convey it at the level that your kids could understand it. (Roger, first interview 4/30/04)

The teachers described their scientific knowledge to be broader, but shallower, than the knowledge of scientists. This category also includes teachers’ knowledge of the nature of science, the scientific process, and of relationship among the various science areas.

Despite much research that dealt with “knowledge of subject matter” as a distinct category within the knowledge bases of a teacher (Carlsen, 1999; Grossman, 1990; Shulman, 1987), the results of this study show that the teachers do not separate this area of knowledge from the area of PCK within the situation of teaching science. Furthermore, four experienced secondary science teachers in the study reported that a strong science knowledge background strengthens them as science teachers and endows them as highly qualified teachers. As Emily stated:

> My strength is my background knowledge in my subject, because I came with a bachelor’s degree in Biology and Chemistry, when I started [teaching] Integrated Science for middle school, it was kind of scary because I did not have a background in Geology or Astronomy. My Physics was kind of weak so that’s why I decided to go back and get the masters in the Integrated Science — to make myself strong. Now when my students ask me a question, I feel confident that I can either, well at this level, it’s pretty much easy to answer whatever question. (Emily, first interview 12/03/03)

*Knowledge of Goal*s.

The teachers link their lessons to the goal of their science classes. They want their students to use scientific knowledge in their real lives and to understand better how things work in the natural world. The following are examples of this area:

> I know obviously that all students I have are not going to college. They are not all going to be a doctors, but I think learning science helps you be a better problem solver and a better thinker and if you are that, then it helps you in any part of your life. (Wendy, second interview 5/18/04)

> My mission is to have every student to believe that they can think like a scientist, act like a scientist and then be a scientist. (Emily, second interview 5/20/04)

Knowledge of Students.

All of the teachers in this study spoke at length about their students. Not only did they know how their students preferred to learn, they also understood their students' lives outside of school. The teachers considered students' interest, different levels of their understanding, their weakness and learning difficulties, and their pre-existing misconceptions in planning lessons and in their teaching practice. Most teachers agreed that "knowledge of science" and "knowledge of students" are the factors that determine the organization of curriculum and teaching strategies. The following excerpts are examples of this area:

> You really learn by working with kids. And when you get out into the classroom you find that the students have many diversified needs and so as we teach, we walk into a classroom, we have a classroom full of so many types of kids so how do you address all their needs in the same time? So you have to pick and choose and

> have quality activities that will address all of their needs. (Shawna, first interview 11/24/03)
>
> I think that our learners have a hard time grasping concepts and making those relationships and I would much rather take more time to cover them than hurry up and get through the material just because it has to be done in a certain part of time. (Shawna, second interview 5/21/04)

Knowledge of Curriculum Organization.

Particularly, most teachers indicated that knowledge or skills in making the connections between scientific concepts, units, and even other subjects is essential. The following are representative data on this area:

> I consider the TEKS and TAKS that I need to teach. I think about this concept and what we will build after it. I also think about related past concepts. For instance, my kids are learning levers and pulleys now. We studied in the spring the human body and we start talking about the skeletal system and the muscular system and I hope to help them understand that within the human body there are levers and pulleys, too. (Emily, first interview, 12/03/03)
>
> I understand the big picture of curriculum. It's very difficult for the teachers to know what should be taught and when to teach it. And, I am a person that does not go by the book. I build my units because kids have certain prerequisites and when you build units you can

> teach across all the subject areas. The textbook can be used as a resource. It should not be the primary factor. (Shawna, first interview, 11/24/03)

Knowledge of Assessment Strategies.

Teachers articulated how they adopted a variety of assessment methods and procedures for ascertaining students' understanding of science concepts. The following are examples of this area:

> When I build on my units, I try to have a lot of different hands-on activities and different types of assessment. It's not quite successful because we get so caught up in dealing with those assessments that we forget performance assessment. So, I tend to build activities that will assess while we are doing. (Shawna, first interview 11/24/03)

> I assess them by their answers on their lab sheet, and there are conclusion questions and you can read from that. Plus they always have a problem and they always write a hypothesis to that problem and then at the end of their lab — after they have answered the conclusion questions — they have to prove or disprove their hypothesis using data from their lab. So if they can tell me, "Yes, my hypothesis is right because when I massed the magnesium before I heated and after I heated it, it showed that it was equal mass so now I know the law of conservation of mass is true." I mean they have got to bring that in. But if they just say, "Yeah, I

> was right," then they have no idea what they were doing. They copied from the person next to them. No. so reading the conclusion part is a good evaluation. (Wendy, second interview 5/18/04)

Knowledge of Teaching Strategies.

Teachers indicated that this knowledge allowed them to adjust their lesson plans to the instructional needs of the students. Most teachers also felt this type of knowledge was a priority as they made connections to real-world applications. The following are examples of this area:

> When we first started with the levers and pulleys, it's really neat because the kids are given the materials and they are given some basic questions. You know: *you put a clip here and if you put the box here*…. And then they start thinking about how to make a lever work. Then they start exploring, and they move into moving the load closer to the floor, moving it farther away — and that moment of "aha!" and then they start saying things like "Oh Miss, I always wondered why they have the handle on the hammer so far away from the head of the hammer." "Oh, now I understand why the longer the screwdriver, the better it is." "Now I understand," and so they start pulling these things into their real lives (Emily, first interview, 12/03/03)

> Not to say that labs are the best things all the time to use. I am beginning to think that you really have to choose your labs wisely.

> Otherwise the amount of time they consume versus the concept that they pick up is not efficient and just because you are supposed to have forty percent lab time doesn't mean that you are getting the best teaching out of that. So, I think it is best to really look at the subject and decide: "Is this going to be better with the lab or just basic teaching methods, lecture, notes and book work?" (Roger, second interview, 5/14/04)

Knowledge of Resources.

Teachers believed their scientific knowledge to be broader, but shallower than the knowledge of scientists. Instead, the teachers suggested, they had a thorough knowledge of resources and materials — in and out of school — that could be used to teach different concepts or topics.

> You have resources available to you, so you begin by using whatever is given to you the first years. And then you reflect on those and the next year you say, "I am going to do it again." or something else comes along, either during your workshops or your professional development. (Roger, second interview 5/14/04)
>
> We get water kits from SAWS, the San Antonio Water System, and so I incorporate that with this at the very same time. So we talk about water conservation. And then we have a blue booklet there, the kids work out of that as well, so it works well with this . (Shawna, second interview, 5/21/04)

CHAPTER FIVE

DISCUSSION, IMPLICATIONS, AND FURTHER RESEARCH

> How much depth does one go when reporting the research? The answer is that, first, the writer must decide on what the main analytic message will be. Then, he or she must give enough conceptual details to convey this to readers. The actual form of the central chapters should be consonant with the analytic message and its components. (Strauss & Corbin, 1998, p. 252)

Overview

This chapter discusses the findings of the study. The first section is the discussion that is generated by the review of the literature and the findings of this study. The next section includes the implications of the study in terms of research, policy, and practice. In closing, the last section includes suggestions for further research.

Discussion

In this section, I highlight and discuss the findings generated in the study. The conclusions of the study are incorporated into the discussion. The main themes of the discussion are reflected in the titles of the sections.

Clarification of Shulman's PCK

The first point I will make pertains to Shulman's work (1987). Shulman theorized the seven categories of knowledge that comprise the necessary base for teaching, including (1) content knowledge; (2) general pedagogical knowledge; (3) curriculum knowledge; (4) pedagogical content knowledge; (5) knowledge of learners and their characteristics; (6) knowledge of educational contexts; (7) knowledge of educational ends, purposes, and values. This seminal paper has been influential in generating numerous studies on teachers' knowledge — particularly PCK — during the past two decades. However, Shulman's work did not provide elucidation of these categories. Given the many studies that addressed the complexity of PCK since Shulman's introduction (Van Driel, et al., 1998; Loughran et al., 2001; 2004), it is clear that Shulman's conception of PCK is still difficult to articulate.

The findings of this study may help to clarify Shulman's notion of PCK. The findings of this study reveal that the PCK components shared in common by the four experienced secondary science teachers includes knowledge of: (1) science; (2) goals; (3) students; (4) curriculum organization; (5) teaching strategies; (6) assessment strategies; and (7) resources. This study clearly shows that these seven components are interrelated within the context of teaching science and play a role as a class of knowledge that is central to science teachers' work. Since this class of knowledge would not typically be held either by scientists or by teachers who know little of science content, I identify this class of knowledge as being PCK that differentiates science teachers from other professionals. Furthermore, it is apparent that the seven components of PCK for science teaching can be meaningful when transformed into a teacher's instructional decisions and actions.

Therefore, on the basis of the findings of this study, the definition of PCK is much broader than "the unique knowledge required for teaching science." It also encompasses "the application of that knowledge by science teachers in their pedagogical decisions and actions to improve students understanding of scientific concepts and to encourage students' scientific inquiry through using effective instructional strategies, representations, and assessment strategies within diverse teaching situations."

Distinctive Terms for the Components of PCK

The third discussion is about the nomenclature employed in this study, with relation to the terminology used in previous studies. It is apparent that the PCK of experienced science teachers consists of many of the qualities described by educational researchers. Specifically, the teachers in our study demonstrated that their notions of PCK included the areas of teaching strategies, students' learning and conceptions, curriculum and media, and assessment. The findings of this study are superficially congruent with those of Grossman (1990), Loughran et al. (2001), Marks (1990), and Tamir (1988). This similarity could be attributed to the use of interview protocols, which was a similar process that used by Grossman (1990), Loughran et al. (2001), Marks (1990), and Tamir (1988) to elicit the PCK of teachers. It could also be that these studies sought to have teachers describe their specialized teaching knowledge. Given that similar categories emerge from the empirical studies including this study, these components seem to prove essential for teaching.

While there are some similarities, there are differences. These differences in terminology may contribute to better understanding of each PCK component.

Practical and Specific Terminologies

Given that the findings of this study show that PCK consists of both knowledge and the application of that knowledge, the terminology for each component of PCK should represent both the knowledge and application piece within PCK. This approach resulted in the creation of more practical and specific terminologies for components and elements than the ones in the previous studies. Taking a closer look at the terminologies for the seven components in this study, one finds that they are more practical and specific, so that one can easily adapt them to various science teaching situations.

Knowledge of curriculum organization.

"Knowledge of curriculum," used by the researchers described in the review of the literature, differs from "knowledge of curriculum organization" in this study. Within this component, the specific elements categorize into two groups. One group includes static knowledge, such as TEKS, TAKS, district standards, curriculum vertical alignment and alignment with other subject areas. The other group includes the ways knowledge is applied, such as how to develop integrated science lessons, how to select what to teach, how to organize lessons in a specific order, and how to make connections between the units and lessons. Since having knowledge elements does not mean that a teacher can apply them to his or her teaching practice, it is likely more practical to include the application elements within the component.

Knowledge of assessment strategies.

Another example is “knowledge of assessment strategies.” Some of the previous research included the “knowledge of assessment” within PCK (Loughran et al., 2001; Magnusson et al., 1999; Tamir, 1988). Despite the fact that the researchers agreed that assessment is not separate from teaching practice, none of these studies provided a detailed description of the assessment component within PCK.

The experienced secondary science teachers in this study considered the assessment component to be a necessary part of their teaching practice — of their PCK. They attributed this to their linkage of assessment to their curriculum organization, their decision about teaching strategies, and to the furtherance of their teaching goals. This result of the study shows that the assessment component also includes both knowledge pieces — a variety of assessment techniques, including formal and informal types of assessment, authentic assessment, quizzes, tests, laboratory journals, and student discussions — and the application pieces — how to initiate student discussion, how to assess student performance, how to respond to student questions, and so on.

Inclusive and Comprehensible Elements within Each Component

The other contribution towards a better understanding of PCK components in this study is its articulation of inclusive and comprehensible elements within each component of PCK. As the conceptualization of PCK has varied greatly, the definitions of PCK components have also fluctuated among the researchers. In comparison to the previous studies related to PCK, the results of this study seem to provide more inclusive and comprehensible elements within each component.

Knowledge of students.

For example, “knowledge of students” in this study refers to students’ different levels of understanding, their different needs and interests, their learning difficulties related to specific science topics, their misconceptions, and their prior knowledge including previous experience and learning. Initially Shulman (1987) indicated only students’ learning difficulties with relation to content. These specific elements within this component draw attention to the aspects of students that should be incorporated into a teacher’s lesson planning and teaching practice.

Knowledge of teaching strategies.

“Knowledge of teaching strategies” in this study refers to a variety of instructional strategies including inquiry types of activities and cookbook laboratories; various representations and materials including demonstrations, simulations, and models; and teachers’ uses of these elements. According to Anderson and Smith (1987), these strategies can be used to “help students change their conceptions, but they must be used in a flexible and responsive manner” (p. 101). The working definition of “teaching strategies” that was used in this study is congruent with the one that Anderson and Smith (1987) described in their work. The four teachers in the study stated how they monitor students’ progress and diagnose students’ misconceptions, and then use that information to promote their students’ understanding of scientific concepts. These experienced teachers are capable of using appropriate teaching strategies without spending a lot of time planning their lessons. They also demonstrate flexibility in adjusting their teaching strategies according to responses from their students.

Along with the assertion of this study — that PCK is not only the knowledge, but also the application of that knowledge into teaching practice, the terminology used in this study will, likewise, be more understandable and useful to those who teach in the classroom. Therefore, the results of this study will provide more applicable guidelines for science teacher educators.

Knowledge of Science and Goals as Base Knowledge

The next point is that "knowledge of science" and "knowledge of goals" serve as base knowledge that governs all of the remaining components of PCK. Notably, all four teachers rated knowledge of science and knowledge of goals highest. Table 4 shows the ratings of each component by the participating teachers. The "knowledge of science" in this study refers to inclusive subject matter knowledge areas related to science — the nature of science, scientific process, and science content per se. Many studies addressed the major role of subject matter knowledge in teaching practice (Gess-Newsome, 1999; Hashweh, 1987; Leinhardt & Smith, 1985; Smith & Neale, 1989; Wilson, Shulman, & Richert, 1987). The results of this study reaffirm the importance of subject matter knowledge in teaching science. Furthermore, all four of the participant teachers agreed that the goals for their science teaching are derived from the knowledge of science. These two interwoven components determine what to teach, how to teach, and what to assess.

Figure 13 shows the scope of the seven components of PCK within teaching science, which summarizes the teachers' rating of each component according to its the importance in science teaching. The results of this study show that the teachers build their curriculum organization upon the base knowledge that includes knowledge of science and knowledge of goals. They also consider their students to be important agents for deciding what to teach (curriculum organization). Based upon these components, the teachers specifically make their instructional decision of how to teach (teaching strategies) and what/how to assess (assessment strategies).They rely upon their knowledge of resources in this decision making process.

Figure 13. The scope of seven PCK components

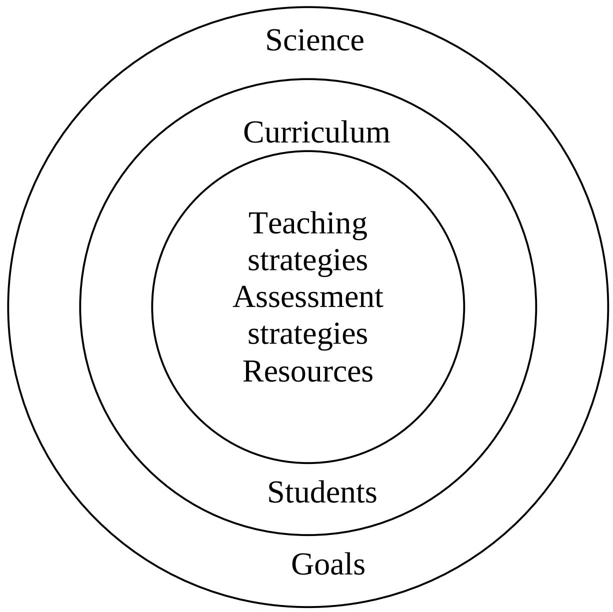


Table 4. The ratings of each component by the teachers according to the importance to teaching science

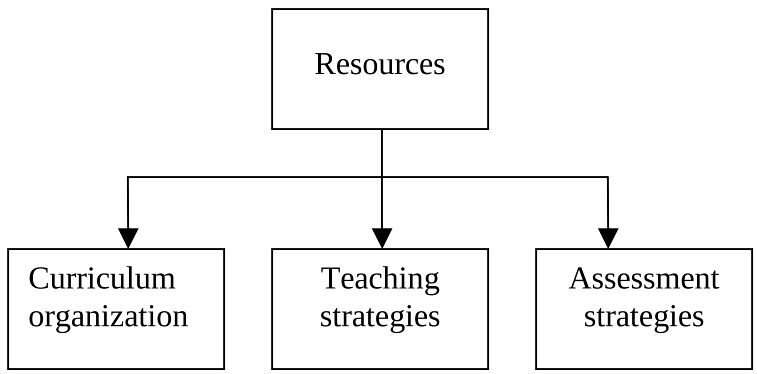
	Wendy	Shawna
Rating	1. knowledge of science	1. knowledge of science
	2-a. knowledge of goals	2. knowledge of assessment strategies
	2-b. knowledge of students	3. knowledge of goals
	3-a. knowledge of teaching strategies	4. knowledge of curriculum organization
	3-b. knowledge of curriculum organization	5. knowledge of students
	3-c. knowledge of resources	6. knowledge of teaching strategies
	4. knowledge of assessment strategies	7. knowledge of resources
	Roger	**Emily**
Rating	1-a. knowledge of science	1-a. knowledge of science
	1-b. knowledge of students	1-b. knowledge of goals
	2-a. knowledge of goals	2-a. knowledge of students
	2-b. knowledge of teaching strategies	2-b. knowledge of curriculum organization
	3. knowledge of resources	3-a. knowledge of teaching strategies
	4. knowledge of assessment strategies	3-b. knowledge of assessment strategies
	5. knowledge of curriculum organization	3-c. knowledge of resources

Knowledge of Resources as a New Strand of PCK

The last point is the "knowledge of resources" component. The teachers in the study discussed an area that had not yet been articulated in the PCK literature. Specifically, they spoke about a need for "knowledge of resources" in teaching science. Given that the experienced secondary teachers are able to design their lessons according to the specific needs and abilities of their students, it is probably even more effective to provide available resources for improving their understanding of science content or for developing materials or activities for their lessons.

While it might seem at first glance that this area is similar to that of "curriculum and media," it is in fact rather distinct. In looking at the literature on "knowledge of curriculum," we noticed that all examples were linked explicitly to published materials made specifically for science instruction. The four participating teachers spoke about resources and materials that were not always published and that often were linked to local science facilities or found in everyday experiences. This unique knowledge component enables science teachers to transform an artifact developed by science facilities or organizations as well as the aforementioned materials or activities into a classroom experience that creates a new learning opportunity. Multimedia and laboratory technology also fall into this component. The teachers recognized multimedia and laboratory technology to be another set of resources that facilitate effective science teaching. Furthermore, the four participating teachers' conceptualizations of PCK show that "knowledge of resources" significantly affects curriculum organization, teaching strategies, and assessment organization (see Figure 14). Therefore, this study suggests that "knowledge of resources" be added to the body of PCK components.

Figure 14. The role of knowledge of resources in science teaching



Implications

This study is expected to be significant in several regards. In the following paragraphs, the implications are discussed in terms of theory, policy, and practice.

Although many educational researchers addressed PCK as a fundamental knowledge for teaching, I am not aware of many empirical qualitative studies of PCK conceptualization with specific regard to science teaching. This attempt to conceptualize PCK from the experienced teachers' perspectives is expected to encourage both researchers in the area and science teacher educators to find new ways to apply teachers' insights into educational pursuits; and to approach, investigate, and facilitate the growth of the PCK of science teachers

The effort to investigate the components that form a science teacher's PCK may communicate to educational policy-makers that traditional teacher education programs are inadequate in that pedagogy and content are not interwoven in the program for professional development. This study also suggests that teacher education programs be enhanced by incorporating the seven components of PCK. The attempt to represent a construct of PCK through the experienced teachers' lenses and the findings of this study will provide an empirical foundation upon which more applicable guidelines for the program development process can be built.

Conceptualizing PCK through experienced science teachers' perspectives may already be a valuable practice in itself, in that this effort can help those in teacher education understand how to construct professional development programs that are conducive to the growth of PCK. This study also provides explicit criteria for practicing teachers to use for developing their own expertise in teaching science.

Further Research

Through this study, I realized that further research over a longer period of time is necessary for better understanding of these teachers' PCK. Given the experiential nature of PCK, I would like to further study how PCK transforms over years of teaching experience. A comparative study between beginning teachers and experienced teachers is likely appropriate to see the difference in their PCK conceptualizations. Conducting a longitudinal study focusing on a teacher's development of PCK would also be useful for capturing the evolutionary features of PCK development.

While working with these mentor teachers, it was apparent that the interactions within the mentoring program may have contributed to the development of PCK for both mentor teachers and beginning teachers. Therefore, further study is required to understand better whether participation in a mentoring program affects PCK development and if so, how.

Despite prolific efforts in this domain over the past two decades, there has been no attempt to codify the domains of this knowledge for practical use. Thus, future study is necessary in order to scale the components and develop a PCK rubric for measuring science teachers' levels of PCK.

Appendices

Appendix A. Timeline

October 2003	-	Obtain approval from DRC/IRB
	-	Observe monthly meeting of the "Teachers as Mentors" program
	-	Recruit study participants
	-	Get demographic information
	-	Collect reflective summaries
November 2003		Conduct first set of interviews
		Transcribe interviews
	-	Collect reflective summaries
December 2003	-	Analyze the first interview data
	-	Get feedback from committee on the process
	-	Collect reflective summaries
January 2004		Reflect the first interview data
	-	Write first interview analysis
	-	Develop second interview questions
February 2004	-	Conduct second set of interview
	-	Transcribe interviews
	-	Collect reflective summaries
March 2004		Analyze data
	-	Get feedback from committee on the process
	-	Collect reflective summaries
April 2004	-	Develop final interview questions
	-	Collect reflective summaries
	-	Write second data analysis
	-	Observe classrooms
May 2004	-	Conduct final interview
	-	Observe classrooms
	-	Transcribe interviews
	-	Collect reflective summaries
June/July 2004	-	Transcribe final interviews
	-	Analyze reflective summaries collected
	-	Analyze final interview data
July/August 2004	-	Summarize data analysis
	-	Member check
	-	Write Literature Review chapter
September/October 2004	-	Write Method, Introduction, Data Analysis chapter
	-	Write Discussion chapter
November 2004/January 2005	-	Write the first draft
	-	Get feedback from committee on the draft

February/April 2005	-	Revise the draft
	-	Dissertation defense
	-	Revise the final draft
May 2005	-	Submit the final copy of dissertation

Appendix B. Informed Consent Form for participants

IRB# *2003-10-0061*

Informed Consent to Participate in Research

The University of Texas at Austin

You are being asked to participate in a research study. This form provides you with information about the study. The Principal Investigator (the person in charge of this research) or his/her representative will also describe this study to you and answer all of your questions. Please read the information below and ask questions about anything you don't understand before deciding whether or not to take part. Your participation is entirely voluntary and you can refuse to participate without penalty or loss of benefits to which you are otherwise entitled.

Title of Research Study:

Defining teachers' knowledge base from the viewpoint of experienced science teachers: A case study of perceptions of effective teaching in mentor science teachers

Principal Investigator(s) (include faculty sponsor), UT affiliation, and Telephone Number(s):

Eunmi Lee
Science Education Center
The University of Texas at Austin
512-232-6207

Funding source: N/A

What is the purpose of this study?

The purpose of this study is to explore effective ways of teaching science from the perspectives of experienced science teachers who serve as mentors to beginning science teachers. The participating mentor teachers from the "Teachers as Mentors" program are invited to participate in the study. Five to seven teachers are anticipated to participate in the study. To document teachers' perceptions, I will conduct semi-structured one-on-one interviews and observations of mentoring activities. I will also utilize monthly reflective summaries of mentor teachers to better understand the teachers' perceptions.

What will be done if you take part in this research study?

By participating in this study, you will be interviewed regarding issues of your perception about teacher's knowledge and your teaching practices. In addition, observations of mentoring activities will be conducted several times during the study period as mutually agreed upon.
At any time, you can withdraw your participation in the study, which will not influence your relationship with the Teachers as Mentors program or Our Lady of the Lake University.

What are the possible discomforts and risks?

There are no known possible discomforts and risks associated with this research study at this time. If you wish to discuss the information above or any other risks you may experience, you may ask any questions now or call the Principal Investigator listed on the front page of this form.

What are the possible benefits to you or to others?

While there are no direct benefits, indirect benefits are apparent. Specifically, you will gain an understanding of your development as a mentor.

If you choose to take part in this study, will it cost you anything?
There are no costs to you to take part in this study.

Will you receive compensation for your participation in this study?
What if you are injured because of the study?

You will not receive compensation of your participation in this study.

If you do not want to take part in this study, what other options are available to you?

Participation in this study is entirely voluntary. You are free to refuse to be in the study, and your refusal will not influence current or future relationships with The University of Texas at Austin, or the mentoring program, or Our Lady of the Lake University.

How can you withdraw from this research study and who should I call if I have questions?

If you wish to stop your participating in this research study for any reason, you should contact: Eunmi Lee at (512) 232.6207 or Dr. Julie Luft at (512) 232.6204. You are free to withdraw your consent and stop participation in this research study at any time without penalty or loss of benefits for which you may be entitled. Throughout the study, the researchers will notify you of new information that may become available and that might affect your decision to remain in the study.

In addition, if you have questions about your rights as a research participant, please contact Clarke A. Burnham, Ph.D., Chair, The University of Texas at Austin Institutional Review Board for the Protection of Human Subjects, (512) 232-4383.

How will your privacy and the confidentiality of your research records be protected?

Authorized persons from The University of Texas at Austin and the Institutional Review Board have the legal right to review your research records and will protect the confidentiality of those records to the extent permitted by law. If the research project is sponsored then the sponsor also has the legal right to review your research records. Otherwise, your research records will not be released without your consent unless required by law or a court order.

If the results of this research are published or presented at scientific meetings, your identity will not be disclosed.

Interviews will be audio taped with your consent. The cassette will be coded so that no personally identifying information is visible on them. The cassettes will be kept in a locked file cabinet in the Principal Investigator's office and will be heard or viewed only for research purposes by the investigator and her associates. Pseudonyms will be used to protect your confidentiality. The cassettes will be destroyed after five years of non-use.

Will the researchers benefit from your participation in this study.

The researcher will not benefit from your participation in this study beyond publishing or presenting the results.

Signatures:

As a representative of this study, I have explained the purpose, the procedures, the benefits, and the risks that are involved in this research study:

__Eunmi Lee____________________________________ ___________________

Signature and printed name of person obtaining consent

Date

You have been informed about this study's purpose, procedures, possible benefits and risks, and you have received a copy of this Form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time. You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights.

____

Printed Name of Subject **Date**

Signature of Subject **Date**

Signature of Principal Investigator **Date**

Consent to be Audio Taped:

I hereby give permission for the interview conducted by Eunmi Lee to be audiotaped and that the audiotapes made for this research study to also be used for educational purposes. I understand that the tapes will be used only for analysis of the interview and only the Principal Investigator will have access to them. The tapes will be kept for five years beyond non-use and will be stored in a locked file cabinet in the office of the Principal Investigator.

Signature of Subject **Date**

Signature of Principal Investigator **Date**

Appendix C. Informed Consent Form for the project director

IRB# <u>2003-10-0061</u>_

Informed Consent to Participate in Research

The University of Texas at Austin

You are being asked to participate in a research study. This form provides you with information about the study. The Principal Investigator (the person in charge of this research) or his/her representative will also describe this study to you and answer all of your questions. Please read the information below and ask questions about anything you don't understand before deciding whether or not to take part. Your participation is entirely voluntary and you can refuse to participate without penalty or loss of benefits to which you are otherwise entitled.

Title of Research Study:

Constructing Pedagogical Content Knowledge (PCK) from teachers' perspective: A case study of perceptions and developments of PCK in mentor science teachers

Principal Investigator(s) (include faculty sponsor), UT affiliation, and Telephone Number(s):

Eunmi Lee
Science Education Center
The University of Texas at Austin
512-232-6207

Funding source: N/A

What is the purpose of this study?

The purpose of this study is to explore experienced science teachers' perceptions of pedagogical content knowledge in teaching science and to redefine pedagogical content knowledge in terms of the perspectives of experienced science teachers who serve as mentors to beginning science teachers. The “Teachers as Mentors” program personnel are invited to participating in this study. In one-on-one interviews with participating mentor teachers and reviews of monthly reflective summaries of mentor teachers, I will conduct observations of the mentoring program activities for a better understanding of the program. I will also conduct semi-structured one-on-one interviews with the program personnel to gain an overview of the program’s mission in the professional development of science teachers.

What will be done if you take part in this research study?

By participating in this study, you will be interviewed regarding issues of pedagogical content knowledge and your teaching practices. In addition, observations of mentoring activities will be conducted several times during the study period as mutually agreed upon. At any time, you may withdraw your participation from the study, and this will not influence your relationship with the “Teachers as Mentors” program or Our Lady of the Lake University.

What are the possible discomforts and risks?

There are no known possible discomforts and risks associated with this research study at this time. If you wish to discuss the information above or any other risks you may experience, you may ask any questions now or call the Principal Investigator listed on the front page of this form.

What are the possible benefits to you or to others?

There are no potential benefits to be gained by you for participating in this study. This study may be beneficial to in-service science teachers participating in “Teacher as Mentors”, a teacher educator directing the mentoring program, and other programs regarding in-service science teacher education.

If you choose to take part in this study, will it cost you anything?

There are no costs to you to take part in this study.

Will you receive compensation for your participation in this study? What if you are injured because of the study?

You will not receive compensation of your participation in this study.

If you do not want to take part in this study, what other options are available to you?

Participation in this study is entirely voluntary. You are free to refuse to be in the study, and your refusal will not influence current or future relationships with The University of Texas at Austin, the mentoring program, or Our Lady of the Lake University.

How can you withdraw from this research study and who should I call if I have questions?

If you wish to discontinue your participation in this research study for any reason, you should contact Eunmi Lee at (512) 232.6207 or Dr. Julie Luft at (512) 232.6204. You are free to withdraw your consent and stop participating in this research study at any time without penalty or loss of benefits for which you may be entitled. Throughout the study, the researchers will notify you of new information that may become available and that might affect your decision to remain in the study.

In addition, if you have questions about your rights as a research participant, please contact Clarke A. Burnham, Ph.D., Chair, The University of Texas at Austin Institutional Review Board for the Protection of Human Subjects at (512) 232-4383.

How will your privacy and the confidentiality of your research records be protected?

Authorized persons from The University of Texas at Austin and the Institutional Review Board have the legal right to review your research records and will protect the confidentiality of those records to the extent permitted by law. If the research project is sponsored then the sponsor also has the legal right to review your research records. Otherwise, your research records will not be released without your consent unless required by law or a court order.

If the results of this research are published or presented at scientific meetings, your identity will not be disclosed.

Interviews will be audio taped with your consent. The cassette will be coded so that no personally identifying information is visible on them. The cassettes will be kept in a locked file cabinet in the Principal Investigator's office and will be heard or viewed only for research purposes by the investigator and her associates. Pseudonyms will be used to protect your confidentiality. The cassettes will be destroyed after five years of non-use.

Will the researchers benefit from your participation in this study.

The researcher will not benefit from your participation in this study beyond publishing or presenting the results.

Signatures:

As a representative of this study, I have explained the purpose, the procedures, the benefits, and the risks that are involved in this research study:

__Eunmi Lee____________________________________ ___________________

Signature and printed name of person obtaining consent **Date**

You have been informed about this study's purpose, procedures, possible benefits and risks, and you have received a copy of this Form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time. You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights.

____

Printed Name of Subject **Date**

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Signature of Subject **Date**

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Signature of Principal Investigator **Date**

Consent to be Audio Taped:

I hereby give permission for the interview conducted by Eunmi Lee to be audiotaped and that the audiotapes made for this research study to also be used for educational purposes. I understand that the tapes will be used only for analysis of the interview and only the Principal Investigator will have access to them. The tapes will be kept for five years beyond non-use and will be stored in a locked file cabinet in the office of the Principal Investigator.

____

Signature of Subject **Date**

____

Signature of Principal Investigator **Date**

Appendix D. First Interview Protocol

1. How many years have you been teaching science?
2. Tell me about your teaching career?

   Since you began teaching, have you always taught science in elementary school (middle school or high school)
3. What are your strengths as a science teacher?
4. How did you acquire those strengths?
5. What are your weaknesses as a science teacher?
6. Tell me about your most successful lesson.
7. Tell me about your least successful lesson.
8. How do you judge whether your lesson is successful or not? Are there any criteria?
9. Let's say two stages of teaching: planning vs. practice

   What do you consider when you plan your science lesson?

   What do you consider when you teach your science class?

10-1. I want you to think about what teacher knowledge is and write down those ideas or categories on the paper.

10-2. Can you draw a picture to graphically (or visually) represent knowledge of a science teacher using those ideas or categories?

OR * Can you show me graphically what teacher knowledge looks like?

OR * Can you draw a representation of what knowledge a science teacher need to know to teach?

10-3. Can you give me an explanation of this drawing?

OR Tell me about this drawing.

(If time allows)

1. How do you decide what (part of curriculum) to teach and what (part of curriculum) not to teach?

2. How do your teaching strategies relate to the discipline of science?
3. What are the reasons that you adopt these strategies to teach science?
4. What are the factors distinguish the science knowledge of teachers from that of scientists?
5. What are the characteristics that demonstrate a science teacher's expertise?
6. What are the factors that influence your teaching?
7. How do you decide your teaching procedures or strategies?
8. What are the obstacles when you teach science in your class?
9. What are the specific ways that you ascertain (make sure) students' understanding or confusion in your class?
10. What factors do you consider important for a beginning teacher to know in order to be a good science teacher?

Appendix E. Second Interview Protocol

1. Tell me about the lesson and unit among curriculum.
2. Why do you consider this important?
3. Why is this unit important for your science students?
4. Can you show me some of highlights of the unit?
5. Tell me about your teaching procedures or teaching strategies and particular reasons for using this to engage with the idea?
6. As you watch the students participate in this unit, what are you thinking as a science teacher?
7. When you developed this unit, what assumptions did you make about students learning and knowledge of the topic?
8. What do you intend for students to learn during this unit?
9. How do you know students understand those ideas or concepts?
10. What are the difficulties and limitations connected with teaching this unit?
11. Can you think of other ways or alternatives to teaching this unit?
12. When you come up some ideas to teach this unit, where are those ideas coming from?
13. What's your ultimate goal for students? What do you want your students to learn thorough your classes?

Appendix F. Third Interview Protocol

These are seven components, which emerged from interview data analysis to define the knowledge area for science teaching. I have several questions to clarify your perceptions related to these components.

1. Can you take a look at it? Feel free to add or modify the components or elements within each component if you want?
2. Would you weigh these components according to the importance with “1” being most important and “7” being least important? If you think any components are similar in importance, you can give them the same rating.
3. Can you make a connection between the components to show how they are interrelated within the notion of teaching science?
4. What kind of term would you give to name the group of seven components of knowledge areas for teaching science?
5. Among those components and elements, which components make teaching science different from teaching other subjects?
6. What is the ultimate goal of your science class?

Bibliography

American Association for the Advancement of Science. (1989). *Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology*. Washington, D.C.: Author.

Austin, T., & Fraser-Abder, P. (1995). Mentoring mathematics and science preservice teachers for urban bilingual classrooms. *Education and Urban Society*, 28(1), 67-89.

Barnett, J. & Hudson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. *Science Education*, 85, 426-453.

Baxer, J.A. and Lederman, N.G., (1999). Assessment and measurement of pedagogical content knowlege. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 147-161). Netherlands: Kluwer Academic Publisher.

Bybee, R. W. & Loucks-Horsley, S. (2001). National Science Education Standards as a catalyst for change: The essential role of professional development. In J. Rhoton & P. Bowers (Eds.), *Issues in science education: Professional development planning and design* (pp. xx-xx). Arlington, VA: NSTA.

Carlsen, W. (1999). Domains of teacher knowledge. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 113-144). Netherlands: Kluwer Academic Publisher.

Cochran, K.F., DeRuiter, J.A., King, R.A. (1993). Pedagogical content knowing: an integrative model for teacher preparation. *Journal of Teacher Education*, 44(4), 263-272

Elbaz, F. (1983) Teacher Thinking: A Study of Practical Knowledge. New York: Nichols Publishing Company.

Feiman-Nemser, S., & Parker, M.B. (1990). Making subject matter part of the conversation or helping beginning teachers learn to teach (Research Report No.90-3). East Lansing: National Center for Research on Teacher Learning.

Fernandez-Balvoa, J. and Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching & Teacher Education*, 11(3). 293-306.

Gess-Newsome, J. (1999). Pedagogical content knowledge: an introduction and orientation. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp.3 – pp.17). Netherlands: Kluwer Academic Publisher.

Glaser, B.G., & Strauss, A.L. (1967). *The discovery of grounded theory: strategies for qualitative research.* New York: Aldine De Gruyter.

Grossman, P.L. (1990) The making of a teacher: teacher knowledge & teacher education. New York: Teachers College Press.

Hashweh, M.Z. (1987). Effects of subject-matter knowledge in the teaching of Biology and Physics. *Teaching & Teacher Education*. 3(2). 109-120.

Huling-Austin, L. (1992). Research on learning to teach. *Journal of Teacher Education*,43(3), 173-180.

Kennedy, M.M. (1991b). Some surprising findings on how teachers learn to teach. *Educational Leadership*, 49 (30, 14-17.

Lincoln, Y. S., & Guba, E. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage.

Loucks-Horsley, S., Hewson, P., Love, N., and Stiles, K. E. (1998). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin.

Loughran, J., Milroy, Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education*. 31, 289-307.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*. 41(4), 370-391.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp.95-132). Netherlands: Kluwer Academic Publisher.

Marks, R. (1990). Pedagogical content knowledge : From a mathematical case to a modified conception. *Journal of teacher education*, 41(3). 3-11.

Merriam, S. B. (1998). *Qualitative research and case study applications in education: Revised and expanded from case study research in education*. San Francisco, CA: Jossey-Bass.

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy.

Odell, S. J. (1986). Induction support of new teachers: A functional approach. *Journal of Teacher Education*, *37*(1), 26-29.

Patton, M. Q. (2002). *Qualitative research and evaluation method* (3rd ed.). Thousand Oaks, CA: Sage.

Shulman, L. S. (1986a). Paradigms and research programs in the study of teaching: A contemporary perspective. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed., pp. 3-36). New York: Macmillan.

Shulman, L. S. (1986b). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*, 1-22.

Strauss, A. & Corbin, J. (1998). Basics of qualitative research: Techniques and procedures for developing grounded theory (2nd ed.). Thousand Oaks:Sage.

Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education*, 4(2), 99-110.

Van Driel, J. H., Beijaard, D., and Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, *38*(2), 137-158.

Wang, J. & Odell, S. J. (2002). Mentored learning to teach according to standard-based reform: A critical review. *Review of Education Research*, *72* (3), 481-546.

Wilson, S. M., Shulman, L.S., & Richert, A.E. (1987). "150 different ways" of knowing: Representations of knowledge in teaching, In. J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 104-124). London: Cassell.

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